Environment International 115 (2018) 343–357

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Review article

Sources of particulate matter in China: Insights from source apportionment studies published in 1987–2017

Yanhong Zhu[a], Lin Huang[a], Jingyi Li[a], Qi Ying[b,a], Hongliang Zhang[c], Xingang Liu[d], Hong Liao[a], Nan Li[a], Zhenxin Liu[a], Yuhao Mao[a], Hao Fang[a], Jianlin Hu[a,*]

[a] Jiangsu Key Laboratory of Atmospheric Environment Monitoring and Pollution Control, Jiangsu Collaborative Innovation Center of Atmospheric Environment and Equipment Technology, School of Environmental Science and Engineering, Nanjing University of Information Science & Technology, 219 Ningliu Road, Nanjing 210044, China

[b] Zachry Department of Civil Engineering, Texas A&M University, College Station, TX 77843-3136, USA

[c] Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge, LA 77803, USA

[d] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China

ARTICLE INFO

Handling Editor: Robert Letcher

Keywords:
China
$PM_{2.5}$
source apportionment
receptor models
regional variations

ABSTRACT

Particulate matter (PM) in the atmosphere has adverse effects on human health, ecosystems, and visibility. It also plays an important role in meteorology and climate change. A good understanding of its sources is essential for effective emission controls to reduce PM and to protect public health. In this study, a total of 239 PM source apportionment studies in China published during 1987–2017 were reviewed. The documents studied include peer-reviewed papers in international and Chinese journals, as well as degree dissertations. The methods applied in these studies were summarized and the main sources in various regions of China were identified. The trends of source contributions at two major cities with abundant studies over long-time periods were analyzed. The most frequently used methods for PM source apportionment in China are receptor models, including chemical mass balance (CMB), positive matrix factorization (PMF), and principle component analysis (PCA). Dust, fossil fuel combustion, transportation, biomass burning, industrial emission, secondary inorganic aerosol (SIA) and secondary organic aerosol (SOA) are the main source categories of fine PM identified in China. Even though the sources of PM vary among seven different geographical areas of China, SIA, industrial, and dust emissions are generally found to be the top three source categories in 2007–2016. A number of studies investigated the sources of SIA and SOA in China using air quality models and indicated that fossil fuel combustion and industrial emissions were the most important sources of SIA (total contributing 63.5%–88.1% of SO_4^{2-}, and 47.3%–70% NO_3^-), and agriculture emissions were the dominant source of NH_4^+ (contributing 53.9%–90%). Biogenic emissions were the most important source of SOA in China in summer, while residential and industrial emissions were important in winter. Long-term changes of PM sources at two megacities of Beijing and Nanjing indicated that the contributions of fossil fuel and industrial sources have been declining after stricter emission controls in recent years. In general, dust and industrial contributions decreased and transportation contributions increased after 2000. $PM_{2.5}$ emissions are predicted to decline in most regions during 2005–2030, even though the energy consumptions except biomass burning are predicted to continue to increase. Industrial, residential, and biomass burning sources will become more important in the future in the businuess-as-usual senarios. This review provides valuable information about main sources of PM and their trends in China. A few recommendations are suggested to further improve our understanding the sources and to develop effective PM control strategies in various regions of China.

1. Introduction

Airborne particulate matter (PM) is a complex mixture of inorganic and organic compounds that exist in either the solid or liquid state. PM can cause atmospheric visibility impairment by scattering and absorbing light (Hyslop, 2009). It also can influence climate directly by scattering and absorbing solar radiation and indirectly by modifying clouds microphysical properties of albedo and lifetime (Solomon et al., 2007). Furthermore, exposure to high levels of PM can cause various human health problems, such as respiratory diseases (Hacon et al.,

* Corresponding author.
E-mail address: jianlinhu@nuist.edu.cn (J. Hu).

https://doi.org/10.1016/j.envint.2018.03.037
Received 15 December 2017; Received in revised form 12 March 2018; Accepted 25 March 2018
Available online 10 April 2018
0160-4120/

2007; Willers et al., 2013) and cardiovascular diseases (Franchini and Mannucci, 2009; Langrish et al., 2012; Ostro et al., 2015).

China has been experiencing severe regional haze pollution in recent two decades, especially in a few key regions such as the North China Plain (NCP) and the Yangtze River Delta (YRD), characterized by extremely low visibility ranges and high $PM_{2.5}$ (PM with aerodynamic diameter equal to or less than 2.5 μm) concentrations (Chan and Yao, 2008; Fu and Chen, 2017; Hu et al., 2014a; Wang et al., 2014f; Zhuang et al., 2014). Recognizing the severity of the haze pollution situation, the Chinese government has set a target in 2013 to reduce $PM_{2.5}$ level by up to 25% in these regions by 2017 (State Council of PRC, 2013). Accurate identification and quantification of $PM_{2.5}$ source contributions are the basis to establish effective control strategies. Therefore, source apportionment studies of $PM_{2.5}$ have become one of the core contents of atmospheric environment research in China.

Accurate source apportionment of PM is complex and difficult, because PM has many primary and secondary components and different components of PM are from different sources. The directly emitted PM is called primary PM, including elemental carbon, primary organic aerosols, minerals, and etc.. In addition, part of PM is formed in the atmosphere through chemical reactions that convert gaseous pollutants (including NO_x, SO_x, and volatile organic compounds (VOCs)) to semi-volatile products that partition to the particle phase. PM formed through atmospheric chemistry processes is called secondary PM, including nitrate, sulfate, ammonium, and secondary organic aerosols (SOA). A variety of sources release PM directly to the atmosphere, including combustion sources (stationary and mobile), food cooking, activities that create dust (road travel and agriculture), and natural sources such as wind-blown dust and sea spray. Ambient measurements have revealed that high primary PM emissions and high secondary PM formation were responsible for severe haze pollution in China (Huang et al., 2014b).

Many source apportionment studies have been conducted in various locations in the United States and Europe since 1960s (Hopke, 2016). Review studies have been conducted to summarize the methods that can be used for source apportionment (Hopke, 2016; Viana et al., 2008) and the sources of regional PM (Belis et al., 2013; Viana et al., 2008). Viana et al. (2008) reviewed 30 years' European publications dealing with source apportionment of PM during 1987 to 2007. The analysis showed that four main source types (PM_{10} and $PM_{2.5}$): a vehicular source, a crustal source, a sea-salt source, a mixed industrial/fuel-oil combustion and a secondary aerosol source (the latter two probably representing the same source type). Their contributions to bulk PM levels varied widely at different monitoring sites, and showed clear spatial patterns in the cases of the crustal and sea-salt sources. Another review by Belis et al. (2013) was conducted focusing on the published literature on source apportionment of PM in Europe using receptor models. Six major source categories for PM were apportioned in Europe: atmospheric formation of secondary inorganic aerosol (SIA) (SO_4^{2-}, NO_3^-, and NH_4^+), traffic, re-suspension of crustal/mineral dust, biomass burning, (industrial) point sources, and sea/road salt. These reviews provide comprehensive understanding of contributions of different sources to PM in these regions.

The first source apportionment study in China was reported in 1987 (Zhang et al., 1987), and since then source apportionment studies have made significant progress in various regions of China due to increasing concerns of severe air pollution problems. Recently, Zheng et al. (2014) summarized $PM_{2.5}$ source apportionment methods and techniques previously and currently applied in China, including sampling preparation, sampler selection, chemical speciation analysis, and source apportionment tools. Zhang et al. (2015b) introduced the development history and characteristics of three main kinds of source apportionment methods (i.e., emission inventory, source-oriented models and receptor models), and discussed the performance differences of the methods using $PM_{2.5}$ chemical components data in Atlanta, USA. More recently, Zhang et al. (2017) reviewed the source apportionment results from 21 cities using the receptor-based method in China, and discussed chemical components and sources of $PM_{2.5}$ in these cities. These review studies provide valuable information of the source apportionment methods that can be applied in China and the sources of $PM_{2.5}$ in multiple locations of China based on receptor models. However, source apportionment studies using air quality models have not been included. Moreover, secondary PM accounts for a large fraction of total PM mass in China, but its sources typically cannot be resolved by the receptor models. Reviews on the sources of secondary PM are necessary to gain a more comprehensive understanding of PM sources in China.

In this study, we reviewed 239 PM source apportionment studies in China published during 1987–2017. We searched China National Knowledge Infrastructure (CNKI) for papers and dissertations in Chinese, and Elsevier ScienceDirect for papers in English, respectively. The key words included sources/source contributions/source apportionment, air quality/particulate matter, and China. The studies included 185 peer-reviewed literatures in Chinese (113) and in English (74), 43 master's theses, and 9 doctoral dissertations. The methods and results in these studies were compiled, and a meta-analysis of the source contributions for PM was conducted to provide a quantitative estimation of the important source types and their contributions in various regions in China. Changes in the source contributions of PM over long term periods were investigated and discussed in locations where such long term data were available.

This review is organized as follows. In Section 2, we reviewed the chronological changes in source apportionment studies and the methods used. In Section 3, we compiled the source apportionment results and identified the major sources of PM in various regions of China. The results of $PM_{2.5}$ are shown in the manuscript and the results of PM_{10} are included in the supplemental materials. In Section 4, we summarized the source contributions of PM in two cities where multiple studies have been taken in different periods over more than a decade time period, and the changes of source contributions were investigated. We also discussed future trends of $PM_{2.5}$ emissions, energy consumption and their sources upon different energy and emission scenarios. In Section 5, we discussed a few issues in the source apportionment studies reviewed in this study. Finally in Section 6, we summarized the major findings and discussed the needs for future PM source apportionment studies in China.

2. Source apportionment studies in China

2.1. Chronological changes in source apportionment studies and methods

Table 1 summarizes the number of PM source apportionment studies in China during different periods. Only a few source apportionment (SA) studies were conducted before 2000. There has been an explosive growth on the number of studies on SA of PM in China since 2010. The SA methods used in these studies are also summarized and listed in Table 1. Some studies utilized multiple methods, so the total number of the methods may be greater than the total number of studies. The methods applied in China can be mainly divided into three general types: (1) receptor models, including chemical mass balance (CMB),

Table 1
Number of particulate matter source apportionment studies in China by applying various methods during different periods compiled in this review in 1980–2016 (This is the study years. The publication year is 1987–2017, the same as Table 2, Table S1, Fig. 1, Fig. 2, and Fig. 4).

Period	Number of studies	CMB	PMF	EF	PCA	FA	AQM	Others
1980–1994	5	4	0	0	0	1	0	0
1995–1999	4	3	1	0	0	0	0	0
2000–2004	39	19	8	2	4	2	7	4
2005–2009	57	15	18	11	19	10	2	9
2010–2016	145	33	57	12	30	13	12	27

positive matrix factorization (PMF), enrichment factor (EF), principle component analysis (PCA), and factor analysis (FA); (2) air quality models (AQM), such as the Community Multi-scale Air Quality model (CMAQ), the Comprehensive Air Quality Model with Extensions (CAMx), the Atmospheric Dispersion Modeling System (ADMS), etc.; and (3) other methods (Others), including isotope ratio, single particle aerosol mass spectrometry, scanning electron microscopes (SEM), ratio analysis, cluster analysis, etc.. Details about the theory of the methods have been provided in previous reviews (Zhang et al., 2015b; Zheng et al., 2014), therefore are not repeated in this study.

Overall, receptor models have been the most popular method for source apportionment studies in China. FA (Zhang et al., 1987) and CMB (Chen et al., 1994) were the early choices for source apportionment studies. The earliest dataset apportioned with PMF was 1998 (Huang et al., 2009), and gradually replaced CMB and became the most popular receptor method. Since 2000, methods used for source apportionment studies become more diverse. PMF, CMB, and PCA have been the most frequently used source apportionment methods in China, accounting for 31.0%, 17.9%, and 16.3% of the studies after 2010. However, AQM accounted for 15.2% more than PCA, becoming the third frequently used SA method during 2000–2004. A few AQM studies have been carried out for regional SA of PM, but the total number (21) is still small compared to the receptor method (262), accounting for only 6.5% of all the studies. Each method has its own features. Results from the CMB model have relatively clear physical meaning as CMB requires detailed profiles for all sources to estimate. Therefore, profile testing for some local sources becomes a first step in order to accurately estimate their contributions. The PMF model does not require known profiles and easy for application. However, it is sometimes difficult to determine the actual sources of the factors identified by PMF. In addition, both CMB and PMF have difficulties to apportion contributions of different sources to secondary pollutants because of the high nonlinearity of the chemical processes. AQM methods can apportion the sources of secondary pollutants and also can determine the contributions from different sources/regions to target locations. However, AQM results are highly affected by the accuracy of emission inventories and the method is technically more difficult for application.

2.2. Source apportionment studies in different regions of China

China has a vast territory with distinct landscape and climate in different parts of China. Studies have revealed substantial variability of PM pollution in different regions of China (Chan and Yao, 2008; Hu et al., 2014a; Hu et al., 2015; Wang et al., 2014f; Zhang and Cao, 2015). The source regions have been grouped into seven parts in this review, following the same definitions in a previous study (Ying et al., 2014): (1) North China, (2) Northeast China, (3) East China, (4) Central China, (5) South China, (6) Southwest China, and (7) Northwest China, as shown in Fig. 1. 86 and 71 studies have been conducted in East and North China, respectively. Relative fewer studies have been conducted in other regions (28, 26, 21, 17, and 16 studies in South, Southwest, Northwest, Central, and Northeast China, respectively). Despite the substantial difference in the number of studies among the regions, the percentages of source apportionment methods used in these studies are similar, as shown in Fig. 1. In general, CMB, PMF, and PCA were the main techniques in all regions, accounting for a total of 44–76.7%. In comparison, AQM method only accounts for 4.5–16.7% of the studies.

Table S1 shows the number of the studies in the five key air pollution regions of China: (1) Jing-Jin-Ji (JJJ) in North China, (2) Yangtze River Delta (YRD) in East China, (3) Pearl River Delta (PRD) in South China, (4) Guanzhong Plain (GZP) in Northwest China, and (5) Sichuan Basin (SCB) in Southwest China. The five regions are characterized by high pollution levels and therefore have been the focus of the SA studies in China. The number of studies for JJJ accounts for 95.8% of the studies in North China, and the fraction is 75.6% for YRD in East China, 75% for PRD in South China, 42.9% for GZP in Northwest China, and 88.5% for SCB in Southwest China, respectively. Table S1 also shows that most of the source apportionment studies using AQM have been carried out in these five key regions, although CMB, PMF, and PCA are still the most frequently used techniques.

3. Major sources of particulate matter in different regions of China

3.1. Sources of bulk PM mass

The source apportionment results in individual studies were extracted and compiled to identify the major sources of PM in various regions of China. Even though direct comparison of different methods applied for different episodes in different studies may lead to some uncertainties in the source contribution estimation, it still provides valuable information about the relative importance of different sources. Seven major source categories were frequently observed in the studies: (1) dust, (2) fossil fuel combustion, (3) transportation emission, (4) biomass burning, (5) industrial emission, (6) SIA (including sulfate, nitrate, and ammonia), and (7) SOA. While SIA and SOA are due to gaseous precursor emissions from many different sources, they are listed as separate source categories here as source contributions to these secondary components were not determined in receptor-based studies. In total, there are 87 studies that have source contributions of secondary aerosols. 69 studies refer to SIA only while 1 study refers to SOA only. 10 studies have estimated the contributions of SIA and SOA from detailed sources, while 7 studies reported SIA and SOA together as secondary sources. Therefore, we summarized the contributions of SIA and SOA using the data in the 80 studies that could count SIA and SOA contributions separately. Table S2 in the supplemental materials shows how different sources reported in the reviewed studies are mapped to the above sources. It should be noted that the above seven identified sources are general categories. Overlap of certain source categories in different studies may exist due to their estimate methods. More discussion of this problem is in Section 5. Fig. 2 illustrates the relative contribution of each source category in the seven regions of China during 1980–2006 and 2007–2016. We chose 2006 to separate the study time because SO_2 and total PM emissions peaked in 2006 and then reduced afterwards due to wide application of flue-gas desulfurization (FGD) devices in coal-fired power plants in response to a new policy of China's government in 2006 (Xu et al., 2009).

Contributions from these sources vary significantly in different regions. In North China, the top three sources are dust, SIA and fossil fuel in 1980–2006, with the average contribution of 25.4%, 23.8% and 18.7%, respectively. Industrial emission, SOA, transportation and biomass burning are also very important sources, accounting for 17.5%, 15%, 11.4%, and 11.0% of $PM_{2.5}$ in this region, respectively. After 2006, industrial emission increased and became the highest contributing source of $PM_{2.5}$, with an average contribution of 28.7% in 2007–2016. The other two top sources are SIA (26.4%) and dust (17.5%). Fossil fuel and transportation are also important sources, contributing to 11.7% and 10.2% of total $PM_{2.5}$ in this region. Biomass burning and SOA are the two least important sources, accounting for 8.7% and 8.5%.

No studies were reported in 1980–2006 in Northeast China. The major sources of $PM_{2.5}$ and their relative contributions in Northeast China in 2007–2016 are similar to those in North China. The top three sources are industrial (22.2%), dust (20.2%), and fossil fuel (18.1%), followed by biomass (18%), SIA (15.6%) and transportation (8.5%). There is only one study conducted in Northeast China for biomass burning during this period. The contribution from SOA is marginal.

In East China, the top three sources are dust, SIA and transportation in 1980–2006, with the average contribution of 33.2%, 22.4% and 19.5%, respectively. Fossil fuel and industrial emission are also very important sources, contributing 18.4%, 16.6%. Biomass and SOA were not identified in the SA studies. After 2006, SIA became the top one source accounting for 39.1% in 2007–2016. Dust, industrial and fossil

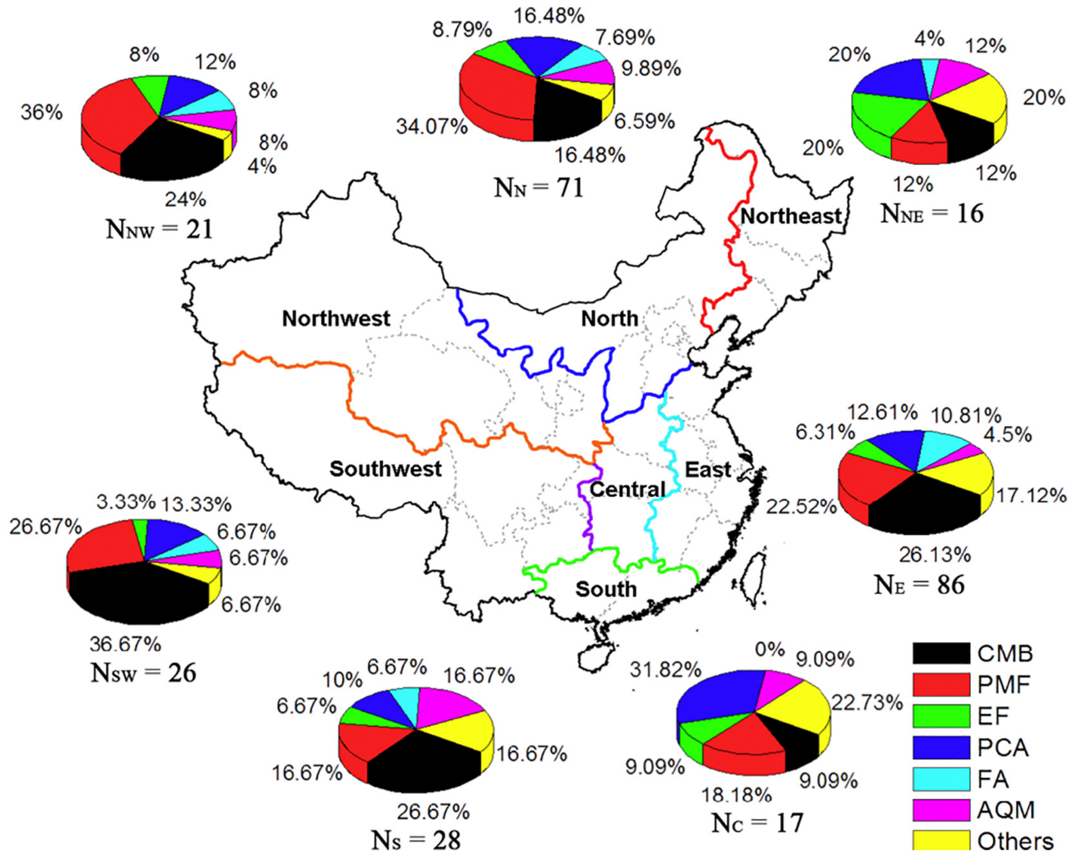

Fig. 1. Distribution of various particulate matter source apportionment methods applied in different regions of China during 1980–2016.
*The references reviewed in each region are as follows.
(1) North China (Cao, 2012; Chen et al., 2013a; Chen, 2007; Chen et al., 1994; Cheng et al., 2007; Cheng et al., 2014; Ding et al., 2010; Ding, 2012; Dong et al., 2013; Dong et al., 2012; Duan et al., 2009; Fang et al., 2016; Fu et al., 2016; Gao et al., 2016; Gao, 2012b; Gu et al., 2010; Gu et al., 2013; Guo, 2015; Han et al., 2016; He et al., 2002; Huang et al., 2014a; Huo et al., 2011; Ji et al., 2006; Kong et al., 2010; Li et al., 2010; Li et al., 2015b; Liang et al., 2015; Liu et al., 2015b; Ma, 2007; Ma et al., 2016a; Meng et al., 2016; Shi, 2010; Shi et al., 2016a; Shi et al., 2016b; Shi et al., 2016c; Shi et al., 2017b; Song et al., 2002; Song et al., 2007; Song et al., 2006a; Song et al., 2006b; Tan et al., 2016b; Tao et al., 2016; Tian et al., 2016b; Wang et al., 2009; Wang et al., 2008; Wang et al., 2016c; Wang et al., 2015a; Wang et al., 2014c; Wang et al., 2015c; Wang et al., 2012b; Wei, 2014; Wei et al., 2015; Wu et al., 2014b; Xu et al., 2007; Yang et al., 2016; Yang et al., 2001; Yang, 2007; Yu et al., 2013; Zhang et al., 2015a; Zhang et al., 2012; Zhang et al., 2016c; Zhang et al., 2013a; Zhang, 2016a; Zhang et al., 2007; Zhao et al., 2009; Zheng et al., 2005; Zhou et al., 2016a; Zhu et al., 1995; Zhu et al., 1996; Zhu et al., 2005)
(2) Northeast China (Fang et al., 2015; Huang and Wang, 2014; Jia, 2014; Liu, 2014; Liu et al., 2015d; Luan et al., 2016; Sha, 2007; Shao, 2004; Shi et al., 2017b; Wang, 2008; Wang et al., 2012a; Wang, 2016; Zhang, 2014a; Zhao et al., 2015; Zheng and Lv, 2015)
(3) East China (An et al., 2014; Bao et al., 2010; Cao et al., 2016; Chen et al., 2013a; Chen, 2011; Chen et al., 2016b; Chen et al., 2016c; Chen et al., 2015b; Chen et al., 2017; Chen et al., 2016e; Chuang et al., 2016; Cui, 2005; Ding et al., 2014; Ding, 2004; Fan et al., 2016; Fan et al., 2005; Feng et al., 2004; Gao, 2012a; Gao, 2012b; Gong, 2013; Gu, 2009; Han et al., 2009; Hou, 2012; Hu et al., 2013; Hu, 2016; Hu et al., 2014b; Huang et al., 2006; Huang et al., 2014a; Huang et al., 2014d; Jiang et al., 2015; Li et al., 2016; Li et al., 2015a; Li, 2013; Li and Li, 2016; Liu et al., 2016a; Liu et al., 2015a; Liu, 2006; Liu et al., 2001; Liu, 2016a; Liu and Gan, 2014; Lu et al., 2008; Peng, 2009; Qi et al., 2016; Qiao et al., 2016; Qin, 2015; Qiu, 2012; Shen et al., 2014; Shi, 2010; Shi et al., 2017b; Tang et al., 2014; Tang et al., 2015; Tao, 2016; Wang et al., 2013; Wang et al., 2016a; Wang et al., 2016b; Wang, 2015a; Wang et al., 2016d; Wang et al., 2015d; Wang et al., 2016e; Wang et al., 2015e; Wang et al., 2015f; Wu et al., 2013b; Wu et al., 2014a; Wu, 2014; Xiao, 2007; Xiao et al., 2012; Xu et al., 2016b; Yan, 2011; Yang, 2008; Yang et al., 2013; Yang et al., 2010; Yao et al., 2016; Yao et al., 2010; Ye, 2011; Yin, 2016; Yu et al., 2015; Yue et al., 2006; Zhang and Chen, 2015; Zhang et al., 2016b; Zhang et al., 2012; Zhang and Zhuang, 2007; Zhang et al., 2016d; Zhang, 2014b; Zhang et al., 2016e; Zhao et al., 2016)
(4) Central China (Chen et al., 2013b; Chen et al., 2015c; Gao, 2012b; Geng, 2012; Kang et al., 2015; Ke, 2015; Liu et al., 2016b; Shi, 2007; Shi et al., 2017b; Song et al., 2016; Wang et al., 2016h; Yang, 2010; Yu et al., 2016; Zeng, 2011; Zhang et al., 2016a; Zhou et al., 2015)
(5) South China (Chen et al., 2016a; Chen et al., 2016d; Cheng et al., 2009; Guo et al., 2009; He, 2006; Ho et al., 2006; Hu et al., 2009; Huang et al., 2014a; Huang et al., 2015; Huang et al., 2009; Huang et al., 2014c; Li, 2007; Li et al., 2013; Li et al., 2012; Liu et al., 2015c; Lu and Fung, 2016; Luo, 2006; Ma et al., 2015; Ma et al., 2016b; Shi et al., 2017b; Song et al., 2015; Tan et al., 2016a; Wu et al., 2013a; Wu et al., 2016; Zhang et al., 2012; Zhao, 2005; Zhou et al., 2016b)
(6) Southwest China (Chen et al., 2015a; Chen et al., 1996; Chen, 2009; Dai et al., 2009; Fan et al., 2015; Jiao et al., 2014; Liang, 2015; Lin et al., 2016; Ren et al., 2014; Shi, 2010; Shi et al., 2017a; Shi et al., 2017b; Sun, 2011; Tao, 2003; Tao et al., 2011; Tao et al., 2006; Tao et al., 2014; Tian et al., 2015; Tian et al., 2013; Wang, 2015b; Xiang et al., 2016; Zhang et al., 2014; Zhang et al., 2012; Zhang, 2016b; Zhang et al., 2013b)
(7) Northwest China (Cao et al., 2005; Dou et al., 2016; Feng et al., 2005; Gao, 2012a; Huang et al., 2014a; Li, 2010; Liu, 2016b; Luo, 2015; Ma et al., 2016a; Qiu et al., 2016; Shi, 2010; Shi et al., 2017b; Tian et al., 2016a; Wang et al., 2014a; Wang et al., 2014b; Wang et al., 2015b; Wang et al., 2016f; Wang et al., 2014e; Xu et al., 2016a; Zhang et al., 1987).

fuel are also very important sources, contributing 18.3%, 17.2%, and 15.9% of $PM_{2.5}$ in this region. Transportation, SOA and biomass account for 14.2%, 12.0% and 8.5%.

In the central region of China during 2007–2016, industrial, SIA and dust are the most important sources, with an average contribution of 28.0%, 26.0% and 23.9%, respectively. Transportation, fossil fuel and SOA account for 16.8%, 12.6% and 10.7%. Biomass burning is not identified as a source of $PM_{2.5}$ in Central China.

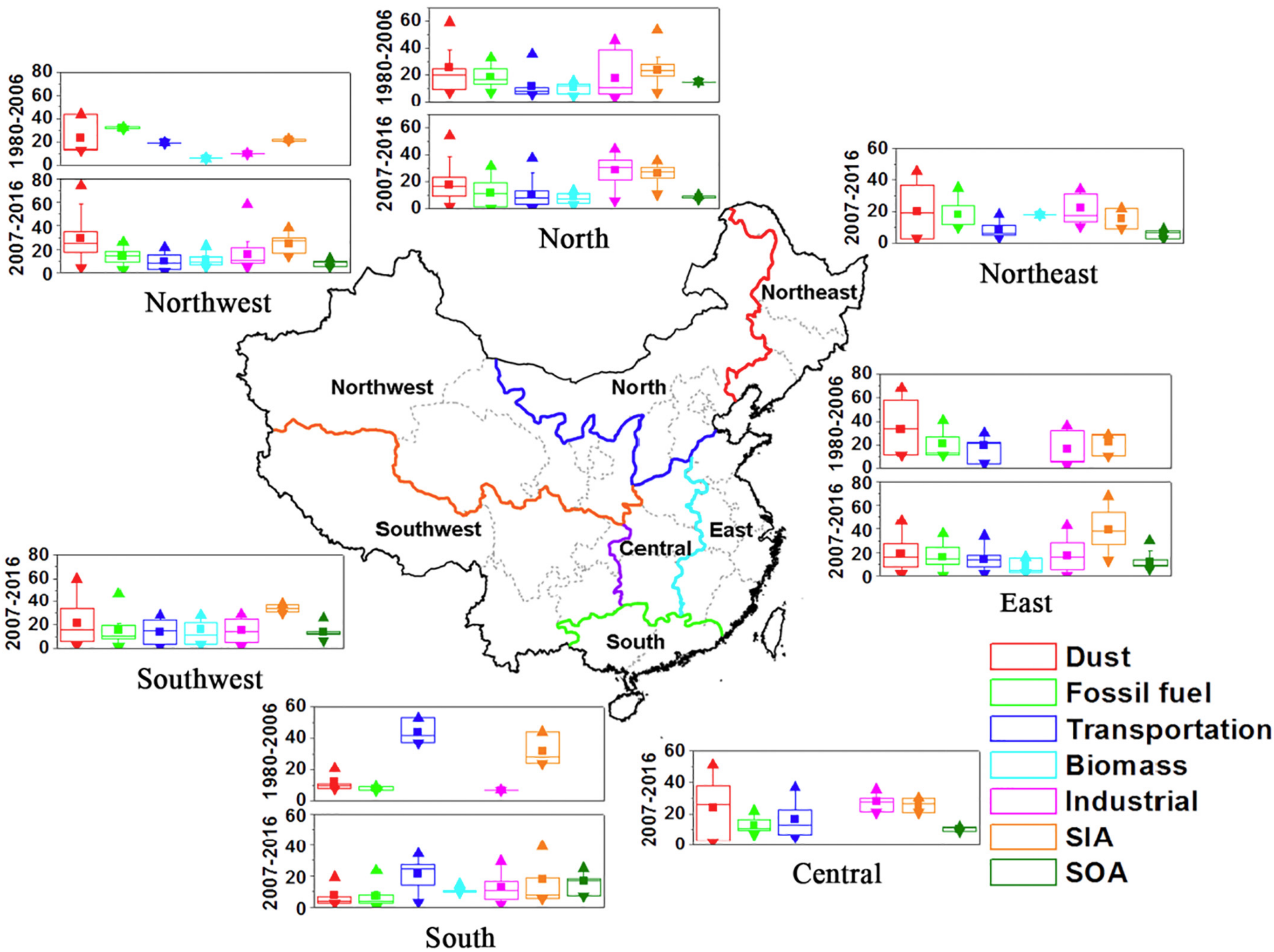

Fig. 2. Major sources of particulate matter in different regions of China during 1980–2016 compiled in this review. The y-axis in each box chart is the contribution (%) of each source type. The maximum, mean, and minimum value are represented by the top edge, middle line, and the bottom edge of each box. The central box represents the values from the lower to upper quartile (25th to 75th percentile). The vertical line extends from the 10th percentile to the 90th percentile. The middle solid line represents the median. The solid squares represent the arithmetic average. Outliers are plotted as triangles.
* The references that we used the data in each region are as follows.

(1) North	1980–2006	(Chen et al., 1994; Gao, 2012a; He et al., 2002; Li et al., 2010; Li et al., 2015b; Song et al., 2007; Song et al., 2006a; Song et al., 2006b; Wang et al., 2008; Yang, 2007; Zhang et al., 2007; Zheng et al., 2005; Zhu et al., 2005)
	2007–2016	(Gao et al., 2016; Gao, 2012a; Guo, 2015; Han et al., 2016; Kong et al., 2010; Li et al., 2015b; Ma et al., 2016a; Meng et al., 2016; Shi et al., 2016a; Shi et al., 2016c; Shi et al., 2017b; Tao et al., 2016; Tian et al., 2016b; Wang et al., 2016c; Wang et al., 2015a; Wang et al., 2015c; Wang et al., 2012b; Wei, 2014; Wei et al., 2015; Wu et al., 2014b; Yang et al., 2016; Yu et al., 2013; Zhang et al., 2016c; Zhang et al., 2013a; Zhang, 2016a)
(2) Northeast	2007–2016	(Huang and Wang, 2014; Jia, 2014; Shi et al., 2017b; Wang, 2016; Zheng and Lv, 2015)
(3) East	1980–2006	(Bao et al., 2010; Fan et al., 2005; Gao, 2012a; Huang et al., 2006; Liu et al., 2015a; Lu et al., 2008; Yue et al., 2006; Zhang and Zhuang, 2007)
	2007–2016	(An et al., 2014; Chen et al., 2016b; Chen et al., 2016c; Chen et al., 2015b; Chuang et al., 2016; Ding et al., 2014; Li et al., 2016; Li et al., 2015a; Liu et al., 2016a; Peng, 2009; Qi et al., 2016; Qiao et al., 2016; Shi et al., 2017b; Wang et al., 2016b; Wang, 2015a; Wang et al., 2015d; Wang et al., 2015e; Wu et al., 2013b; Wu, 2014; Xiao, 2007; Xiao et al., 2012; Xu et al., 2016b; Yan, 2011; Yang et al., 2013; Yang et al., 2010; Yao et al., 2016; Ye, 2011; Yu et al., 2015; Zhang, 2014b)
(4) Central	2007–2016	(Chen et al., 2015c; Geng, 2012; Kang et al., 2015; Shi et al., 2017b; Wang et al., 2016h; Yang, 2010; Zhou et al., 2015)
(5) South	1980–2006	(Guo et al., 2009; Ho et al., 2006)
	2007–2016	(Chen et al., 2016a; Huang et al., 2015; Huang et al., 2014c; Shi et al., 2017b; Song et al., 2015; Tan et al., 2016a; Wu et al., 2013a)
(6) Southwest	2007–2016	(Chen, 2009; Dai et al., 2009; Fan et al., 2015; Jiao et al., 2014; Liang, 2015; Lin et al., 2016; Ren et al., 2014; Shi et al., 2017a; Shi et al., 2017b; Tao et al., 2014; Tian et al., 2015; Tian et al., 2013; Wang, 2015b; Zhang et al., 2013b)
(7) Northwest	1980–2006	(Gao, 2012a; Xu et al., 2016a; Zhang et al., 1987)
	2007–2016	(Dou et al., 2016; Liu, 2016b; Luo, 2015; Qiu et al., 2016; Shi et al., 2017b; Wang et al., 2014a; Wang et al., 2014b; Wang et al., 2015b; Wang et al., 2016f; Wang et al., 2016g; Xu et al., 2016a)

Table 2
Top three sources in each region over China during 2007–2016.

Region	1st source	2nd source	3rd source
North	Industrial	SIA	Dust
Northeast	Industrial	Dust	Fossil fuel
East	SIA	Dust	Industrial
Central	Industrial	SIA	Dust
South	Transportation	SIA	SOA
Southwest	SIA	Dust	Biomass
Northwest	Dust	SIA	Industrial

In South China, the contributions from transportation and SIA are remarkably significant, with mean values of 44% and 32% in 1980–2006, and 21.5% and 17.8% in 2007–2016, respectively. Dust contributes to 12.4% of $PM_{2.5}$, followed by the fossil fuel contribution of 8% in 1980–2006. In 2007–2016, SOA, industrial and biomass are also very important sources, contributing to 16.8%, 12.9% and 11.4% of $PM_{2.5}$, followed by dust (7.7%) and fossil fuel (7.0%).

Southwest and Northwest China share the same top two sources of $PM_{2.5}$, which are SIA (33.4% vs. 24.5%), and dust (21.3% vs. 29.0%) in 2007–2016. In 1980–2006 these two sources in Northwest account for 21.6% and 23.3%, respectively. Biomass, fossil fuel, industrial emission, SOA and transportation are also important sources in Southwest, contributing to 16.1%, 15.7%, 15.4% 14.2% and 14.1% of $PM_{2.5}$ in 2007–2016. Fossil fuel (31.8%), transportation (19.3%) in 1980–2006 and industrial sources (15.6%) in 2007–2016 have significant contributions in Northwest.

The top three sources in each region over China during 2007–2016 are summarized in Table 2. It is obvious that SIA, dust and industrial emission are generally the most important three sources for $PM_{2.5}$ in almost all regions over China, due to a huge backer of infrastructure projects and large amount of industrial production. The situation is slightly different in South, Northeast and Southwest China. In South China, the influence of transportation and SOA source becomes more important due to relatively more motorization, while in Northeast/Southwest China, fossil fuel/biomass is a very important source due to large amount of coal combustion for residential heating/field burning of crop residue.

3.2. Sources of SIA and SOA

SIA and SOA account for a large fraction of $PM_{2.5}$ in China (Huang et al., 2014b), the contributions from different sources to SIA and SOA need to be estimated to design effective emission control programs. Source apportionment of SIA and SOA typically cannot be resolved by the receptor models, and AQM models are usually used to determine the source contributions of SIA and SOA. Source contributions of SIA in $PM_{2.5}$ are summarized from available AQM source apportionment studies in China. These studies used different AQM models including CMAQ (in 11 studies) and CAMx (in 5 studies). Other models used include the ADMS and AERMOD dispersion models and a nested air quality prediction modeling system (NAQPMS) (in 4 studies). Different source apportionment methods such as brute force (in 6 studies), non-reactive tracer method (in 8 studies), and source-oriented methods (in 6 studies) have been applied. It should be noted that due to the complex non-linear dependencies to precursor emissions in the SIA formation, negative or over 100% contributions may appear when using the brute force source apportionment method. Fig. 3 shows the results of SIA in different regions. Fig. 3a shows that fossil fuel and industrial sources combined account for 63.5%–88.1% of SO_4^{2-} in all regions. Residential emissions are also important, accounting for 9.3%–13.6%, except in the PRD and YRD regions. Contributions from transportation emissions to SO_4^{2-} are generally low except in one study in PRD (Lu and Fung, 2016) which estimated relatively large emissions of SO_2 from vehicles. For NO_3^-, as shown in Fig. 3b, fossil fuel and industrial emissions are still the most important sources (47.3%–70%), which are similar to their relative contributions to SO_4^{2-}. But different from SO_4^{2-}, transportation contributes to 22%–34% of NO_3^- in all regions. Agriculture is the primary source of NH_4^+ (53.9%–90%) in all regions, as shown in Fig. 3c. The sources and their contributions to SIA in some cities are shown in Fig. S1 in the supplemental materials.

Only a few source apportionment studies of SOA were reported in the literature. Cheng et al. (2009) estimated the source contributions to SOA in fall of 2004 in the PRD region using the two-dimensional model with the brute force method. The study found that biogenic, transportation, point, and solvent and oil paint sources accounted for 72.6%, 30.7%, 12% and 12% of $PM_{2.5}$, respectively (note that the total is over 100% by the brute force method). Wang et al. (2017) applied CMAQ model with a source-oriented SOA module and found that biogenic emissions contributed significantly to SOA in summer (68.7%) and industrial (39%) and residential (42.2%) sources were the main winter SOA contributors in China when using the Multi-resolution Emission Inventory for China (MEIC). However, the study also indicated that the source contributions to SOA could be substantially different when using the Regional Emission inventory in ASia v2.1 (REAS2), although the total predicted SOA concentrations were similar. More studies on the source contributions to SOA are needed to have a comprehensive understanding about the sources of SOA in China.

4. Changes in source contributions of particulate matter in two cities of China

Only three cities (Beijing, Nanjing, and Chongqing) were found to have multiple source apportionment studies conducted in different years over more than a decade. The results of Chongqing are of TSP and PM_{10} and only have 1 or 2 studies during the 5-year periods, therefore the data in Chongqing were not used. The results were compiled and shown in Fig. 4. Fig. 4a presents the $PM_{2.5}$ averaged concentrations and the relative contributions to $PM_{2.5}$ from each source during five five-year periods between 1985 and 2016 (i.e. 1985–1989, 1995–1999, 2000–2004, 2005–2009, 2010–2016; no studies for 1990–1994 were found) in Beijing. The averaged $PM_{2.5}$ concentrations were 78.5, 142 ± 4, 108.1 ± 19.4, 107.5 ± 31.8, and 86.8 ± 25.0 $\mu g/m^3$, respectively. The major sources were transportation emission, fossil fuel combustion and dust in 1985–1989. Source contribution of transportation decreased sharply from 35.7% in 1985–1989 to 8.7% ± 0.2% in 1995–1999, 10.3% ± 7.5% in 2000–2004 and 5.7% ± 2.6% after 2005–2009, but increased to 14.5% ± 8.9% after 2010. The contribution from fossil fuel combustion decreased to 12.3% ± 6.5% in 2005–2009 but increased slightly to 15.0% ± 6.6% after 2010. The contribution from dust source dropped down from 24.1% in 1985–1989 to 13.6% ± 7.4% in 2010–2016, except for an increase of 30.5% ± 18.7% in 2005–2009. SIA source has become the major source ever since 1995 and increased to 25.4% ± 1.9% after 2010. The percentage from industrial source was as low as 13.8% ± 0.7% in 1995–1999, and then prominently increased to 21.3% ± 15.0% in 2005–2009. The contribution from industrial sources decreased to 14.6% ± 12.8% after 2010 possibly due to emission controls. There is little change in the contribution of biomass burning (approximately 10% ± 3.4%) since 2000. The contribution of SOA was estimated in only a few studies during 2000–2004 and after 2010, and therefore the long-term trend of its contribution to $PM_{2.5}$ cannot be determined.

Fig. 4b shows the changes in percentage source contributions to $PM_{2.5}$ during 2000–2016 in Nanjing. No data were available before 2000 in Nanjing. The most significant change in Nanjing is that the contribution from SIA source had boomed from 10.5% to 43.9% ± 21.2% since 2000. Dust source contribution decreased from more than half in 2000–2004 to 10.2% ± 9.9% during 2010–2016. Fossil fuel combustion also exhibits a declining trend. It accounts for 22.4% ± 8.6%/27.2% of $PM_{2.5}$ in 2000–2004/2005–2009 but its contribution decreases to 10.7% ± 8.3% in 2010–2016. The highest

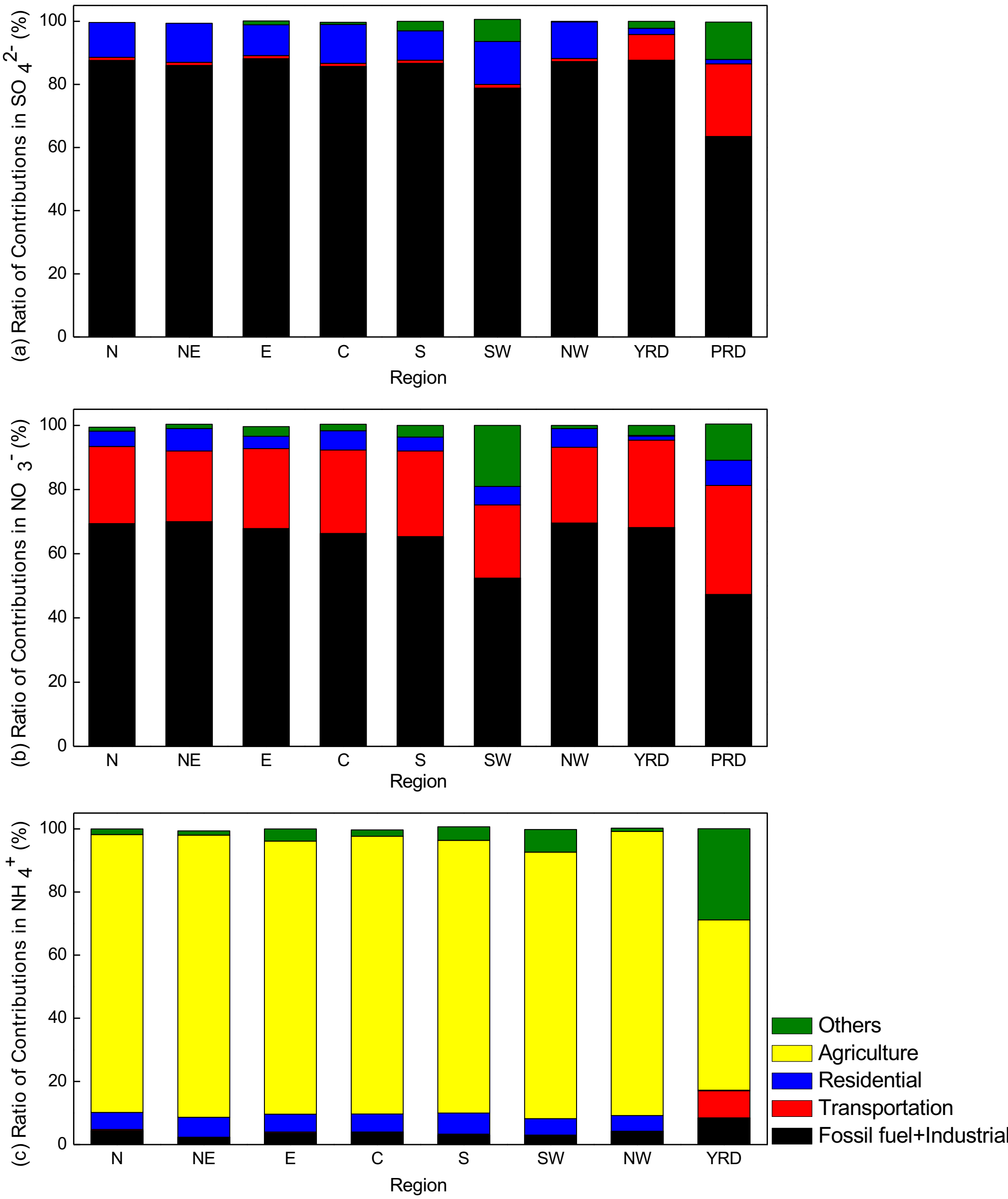

Fig. 3. Sources and contributions to $PM_{2.5}$ (a) SO_4^{2-}, (b) NO_3^- and (c) NH_4^+ in the regions of China using AQM.
*N = North China, NE = Northeast China, E = East China, C = Central China, S = South China, SW = Southwest China, NW = Northwest China, YRD = Yangtze River Delta, PRD = Pearl River Delta.
* The references that we used the data and their methods in each region are as follows.
(1) N, NE, E, C, S, SW, NW: (Shi et al., 2017b) CMAQ
(2) PRD: (Lu and Fung, 2016) WRF (Weather Research Forecast) and SMOKE (Sparse Matrix Operator Kernel Emission)-CAMx modeling system with PSAT (particulate source apportionment technology) module
(3) YRD: (Li et al., 2015a) PSAT method coupled within CAMx.

relative contribution of industrial source to $PM_{2.5}$ (20.2%) occurred during 2005–2009. This was significantly higher than the percentage contribution of 4.6% ± 1.3% in 2000–2004 and 9.6% ± 6.4% after 2010. Similar to Beijing, the contribution from transportation source showed an obvious increase from 4.0% in 2000–2004 to 17.8% ± 6.3% in 2010–2016.

Central and local Chinese governments recently have developed emission control policies aiming to improve air quality before 2030. Control policy contributing to reductions of $PM_{2.5}$ emissions include energy-saving measures, e.g., energy efficiency improvements, cogeneration of heat and power, fuel substitution, and end-of-pipe control measures such as installations of dust collectors and flue gas desulfurization systems. The policies have led to the source emission trends that partly have been observed in Fig. 4, but also will drive the future emission trends. Fig. 5 illustrates future trends of $PM_{2.5}$ emissions, energy consumption and $PM_{2.5}$ emission rate from the major sources in China during 2005–2030. The calculation of $PM_{2.5}$ emission rate is $PM_{2.5}$ emissions / energy consumption ∗ 100. The data are derived from the study of Wang et al. (2014d) and the references therein. Two energy scenarios business-as-usual (BAU) and alternative policy (PC) are discussed. The BAU scenario is based on that current regulations and implementation status will be continued during 2011–2030. The PC

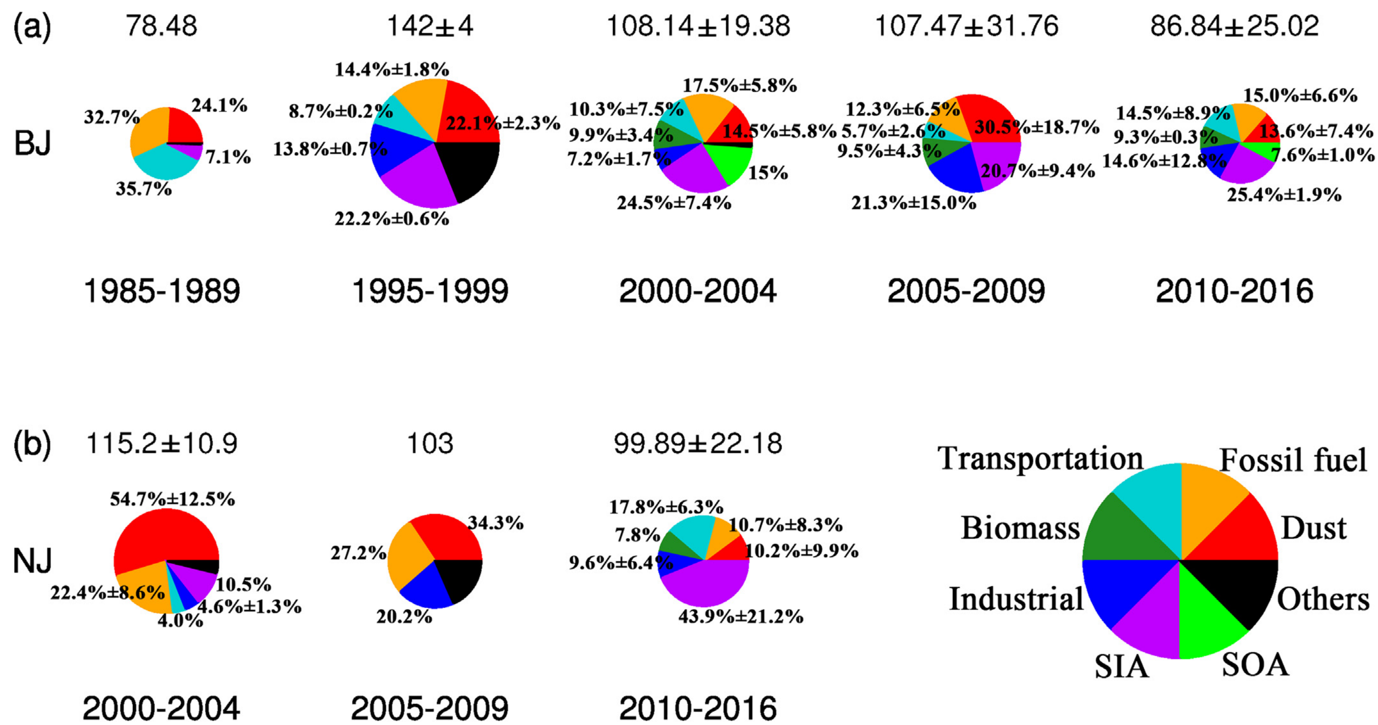

Fig. 4. Chronological changes in source contributions of $PM_{2.5}$ in (a) Beijing (BJ) and (b) Nanjing (NJ) considered in this review. Units are μg/m^3.
*The references that we used the data in each city are as follows.

(1) Beijing	1985–1989	(Chen et al., 1994)
	1995–1999	(He et al., 2002)
	2000–2004	(Song et al., 2007; Song et al., 2006a; Song et al., 2006b; Wang et al., 2008; Zhang et al., 2007; Zheng et al., 2005; Zhu et al., 2005)
	2005–2009	(Gao, 2012a; Li et al., 2015b; Tao et al., 2016; Wang et al., 2009; Wang et al., 2008; Yang, 2007; Zhang et al., 2013a)
	2010–2016	(Gao et al., 2016; Han et al., 2016; Li et al., 2015b; Shi et al., 2017b; Wang et al., 2015c; Wang et al., 2012b; Wu et al., 2014b; Yang et al., 2016; Yu et al., 2013; Zhang et al., 2016c)
(2) Nanjing	2000–2004	(Fan et al., 2005; Huang et al., 2006)
	2005–2009	(Yang et al., 2010)
	2010–2016	(Chen et al., 2015b; Ding et al., 2014; Hu et al., 2013; Li et al., 2016; Qi et al., 2016; Wang et al., 2016a; Wang et al., 2015d)

scenario assumes that new energy saving policies will be released and more strongly enforced starting from 2011, resulting in lifestyle changes, structural adjustment, and energy efficiency improvement. Only the data that correspond with main $PM_{2.5}$ emission sources in Fig. 5 were used. Fig. 5a shows that BAU and PC have the same effects on biomass, residential and transportation sources. Residential, biomass and transportation source increase from 2005 to 2010 and decrease then. Industrial source decreases all the time in 2005–2030. Power plant decreases after 2005 but increases a little in 2020. Fig. 5b shows the energy consumption of china in 2005–2030. All of energy consumptions except biomass burning increase during 2005–2030 in two energy scenarios. Fig. 5c shows that $PM_{2.5}$ emission rates of transportation and power plant are lower than other three sources. Residential and biomass source increase from 2005 to 2010 and then decrease while other sources decrease from 2005 to 2030. Biomass source with BAU has lower $PM_{2.5}$ emission rates than PC and residential source is just the opposite.

5. Discussion

Receptor models are the most common source apportionment methods used in China. However, major source categories and their source contributions estimated by different receptor models may be different even though the data come from the same place in the same time because many of the methods do not have a unique solution and many source tracers used to identify sources are not unique to a specific source (Zhang et al., 2015b). Zhang et al. (2015b) analyzed $PM_{2.5}$ and its chemical component at Atlanta in July, 2001 using various tracers and methods such as CMB-LGO (Lipschitz Generalized Optimization), CMB-MM (Molecular Marker), PMF, and CMAQ. The source categories were different, and therefore the contribution percentage of each source was different. Another comparative study also shows the difference in the source apportionment results using the PMF, CMB and FA models (Chen, 2011). Thus, the source contributions assembled in this study might have significant uncertainties by directly incorporating source apportionment results with different methods. However, the conclusion that dust, coal combustion, transportation emission, biomass burning, industrial emission, SIA and SOA were main sources of $PM_{2.5}$ in China is likely robust.

AQM studies can provide information of sources of SIA and SOA. However, the application of AQM in China is still relatively limited and has mainly focused on the five key air pollution regions. More AQM source apportionment studies should be conducted in China, especially in the less-studied regions. Different models and different source apportionment techniques have been used, leading to some uncertainties in the direct comparison of the results. Comparisons of different AQM models with different techniques should be conducted. In addition, the accuracy of AQM source apportionment results is often limited by the uncertainties in the emission inventories. Therefore, comparisons of AQM and receptor models should also be conducted in order to build confidence on the robustness of source apportionment results and reduce uncertainties in emission inventories.

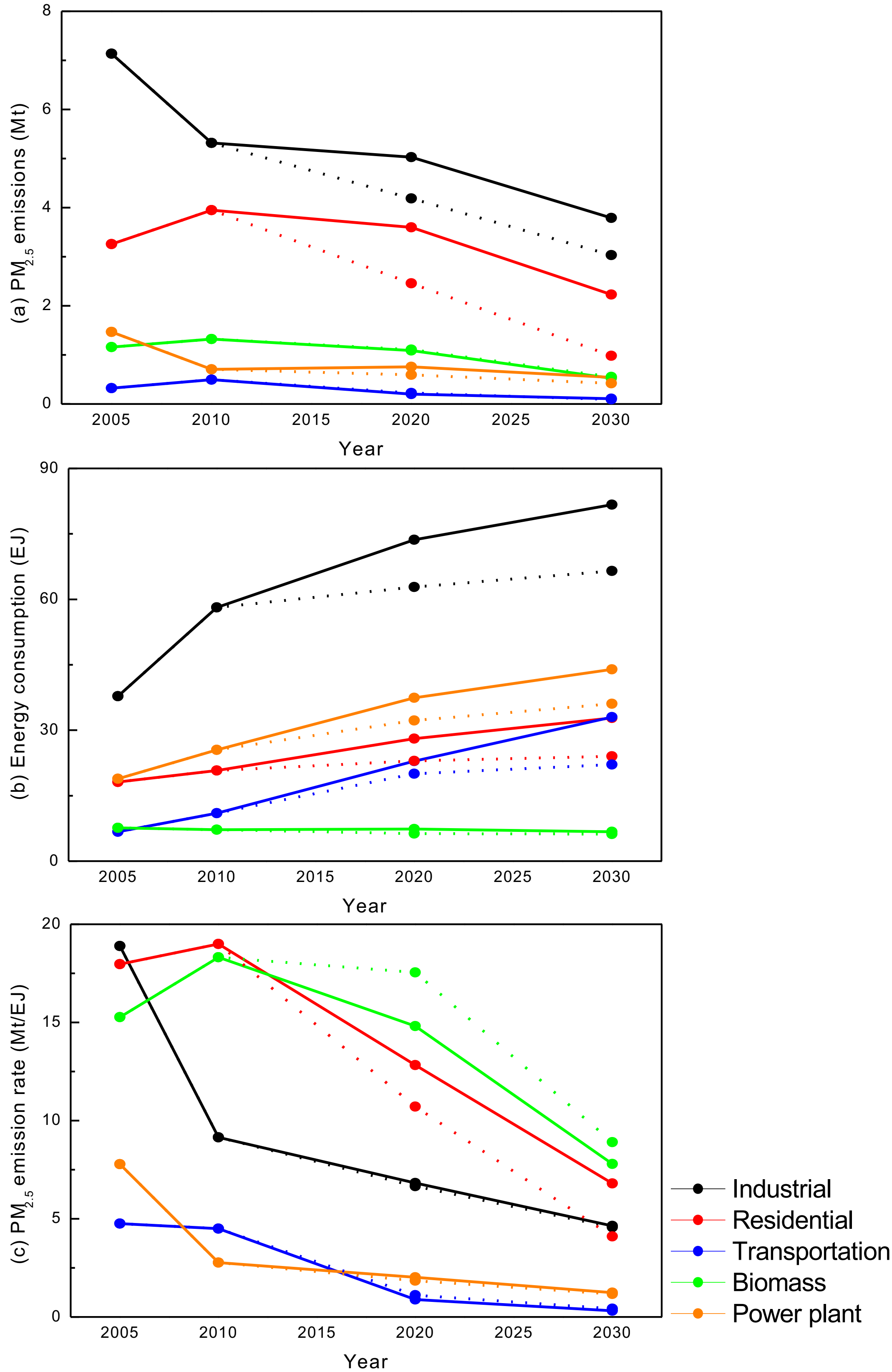

Fig. 5. Future trends of each source about (a) $PM_{2.5}$ emissions, (b) energy consumption, (c) $PM_{2.5}$ emission rate of China during 2005–2030. The data of Taiwan, Hong Kong and Macao are not included. Straight line represents BAU and dotted line represents PC.

China has been undergoing fast economy and society development. The analysis of major sources of $PM_{2.5}$ and their trends available at three cities indicated the sources have also undergone substantial changes. Long-term source apportionment studies are highly valuable for developing effective air pollution control strategies, evaluating the effectiveness of designed strategies as well as evaluating the adverse health effects due to exposure to air pollution. Such studies should be recommended in more cities/regions of China.

Most of the studies identified and estimated contributions from 6 to 8 source categories. The definitions of the source categories usually are general with many sub-source categories. For example, industrial source category includes many different industries, and transportation source category includes all vehicle types with all fuel types. Developing cost-effective emission control strategies requires more accurate analyses of the contributions from detailed sub-categories, many of them cannot be readily determined using receptor models due to collinearity and/or lack of source-specific tracers. Developing methods to resolve these sub-source categories should be a future research priority in China.

6. Conclusions

239 studies on source apportionment of $PM_{2.5}$ in China published during 1987–2017 were summarized to provide a better understanding of $PM_{2.5}$ sources for effective pollution abatement. By analyzing the methods that have been applied in these studies, identifying the main sources of particulate matter, and investigating the trends of the main sources over the years, the follow findings were made:

(1) Source apportionment studies have been conducted in various locations of China, mainly in the five key regions of JJJ in North China, YRD in East China, PRD in South China, GZP in Northwest China, and SCB in Southwest China. Sources and their contributions to $PM_{2.5}$ are still not well understood in many other regions.
(2) Up to date, the receptor models of CMB, PMF and PCA are the most frequently used methods for PM source apportionment studies in China. A few AQM source apportionment studies have been carried out, but mostly in the five key regions.
(3) Dust, fossil fuel combustion, transportation emission, biomass burning, industrial emission, SIA and SOA are identified to be the main sources of $PM_{2.5}$ in China, while SIA, dust and industrial emission were the most important sources of particulate matter in seven geographical areas during 2007–2016.
(4) A limited number of studies investigated the sources of SIA and SOA in China using regional air quality models. These studies indicated that the important sources of SIA include coal and industry (63.5%-88.1%) for SO_4^{2-}, coal and industry (47.3%-70%) and transportation (22%-34%) for NO_3^-, agriculture (53.9%-90%) for NH_4^+, respectively. Biogenic emissions are an important source of SOA in fall and summer, while residential and industrial sources are important in winter.
(5) Source contributions of PM have undergone substantial changes at Beijing and Nanjing. In general, dust and industrial contributions decreased and transportation contributions increased after 2000. The importance of the sources changes with different trends in various cities over the past 30 years.
(6) $PM_{2.5}$ emissions are predicted to decline in most regions during 2005–2030, even though the energy consumptions except biomass burning are predicted to continue increase. Industrial, residential, and biomass burning sources will become more important in the future in the businuess-as-usual senarios.

A few recommendations for future source apportionment studies in China can be made based on this comprehensive review of existing source apportionment studies:

(1) Inter-comparison of the different methods and evaluating the robustness of the models for applications in various regions of China are highly valuable and should be considered in future. The comparison studies include inter-comparisons among different receptor models, among different AQM models, as well as comparisons of receptor models and AQM models.
(2) More source apportionment studies using the AQM methods and other advanced methods such as isotope ratio and single particle aerosol mass spectrometry methods should be encouraged in China and more source apportionment studies on SIA and SOA should be conducted considering that SIA and SOA account for large fractions of PM. Accurate emission inventory are needed for AQM studies.
(3) Long-term source apportionment studies are recommended in more cities/regions to reflect the fast changing sources of China in different regions.
(4) Future source apportionment studies should identify and estimate contributions from more detailed sources other than broad source categories to provide quantitative information for accurate and effective emission control.

Acknowledgement

This work was supported by the National Key R&D Program of China (2016YFC0203500, Task #2); the National Natural Science Foundation of China (41675125, 91544221); the Natural Science Foundation of Jiangsu Province under contract no. BK20150904; Public Welfare Projects for Environmental Protection (201509001); Jiangsu Distinguished Professor Project 2191071503201; Jiangsu Six Major Talent Peak Project 2015-JNHB-010; and the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2018.03.037.

References

An, J., Li, L., Huang, C., Wang, Y., Huang, H., Chen, C., Yan, R., Li, H., Zhou, M., Lu, Q., Qiao, L., Lou, S., Wang, H., Wang, Q., Chen, M., 2014. Source apportionment of the fine particulate matter in Shanghai during the heavy haze episode in eastern China in January 2013. Acta Sci. Circumst. 34, 2635–2644 (Chinese).
Bao, Z., Feng, Y., Jiao, L., Hong, S., Liu, W., 2010. Characterization and source apportionment of PM2.5 and PM10 in Hangzhou. Environmental Monitoring in China 26, 44–48 (Chinese).
Belis, C.A., Karagulian, F., Larsen, B.R., Hopke, P.K., 2013. Critical review and meta-analysis of ambient particulate matter source apportionment using receptor models in Europe. Atmos. Environ. 69, 94–108.
Cao, S., 2012. Sources Apportionment of PM10 and PM2.5 in Five Cities in China. Tianjin Medical University, Tianjin.
Cao, J., Wu, F., Chow, J.C., Lee, C., Li, Y., Chen, S., An, Z., Fung, K.K., Watson, J.G., Zhu, C., Liu, S., 2005. Characterization and source apportionment of atmospheric organic and elemental carbon during fall and winter of 2003 in Xi'an, China. Atmos. Chem. Phys. 5, 3127–3137.
Cao, L., Zhu, Q., Huang, X., Deng, J., Chen, J., Hong, Y., Xu, L., He, L., 2016. Chemical characterization and source apportionment of atmospheric submicron particles on the western coast of Taiwan Strait, China. J. Environ. Sci. 1–12.
Chan, C.K., Yao, X., 2008. Air pollution in mega cities in China. Atmos. Environ. 42, 1-42.
Chen, D., 2007. Study on the Influence of Air Quality in Beijing by Surrounding Regions and Atmospheric Assimilative Capacity. Beijing University of Technology, Beijing.
Chen, T., 2009. Study on Source Apportionment of Fine Particulate Matter in Central Chengdu. Xi'an Jiaotong University, Xi'an.
Chen, F., 2011. Comparative Study on PMF, CMB and FA Models of Sources Apportionment of Atmospheric Particulates. Jilin University, Changchun.
Chen, Z., Ge, S., Zhang, J., 1994. Measurement and analysis for atmospheric aerosol particulates in Beijing. Res. Environ. Sci. 7, 1–9 (Chinese).
Chen, S., Zheng, Y., Zhao, Q., Meng, M., 1996. Source analysis of air particulate pollution in Chongqing. Chongqing Environ. Sci. 18, 24–28 (Chinese).
Chen, B., Andersson, A., Lee, M., Kirillova, E.N., Xiao, Q., Krusa, M., Shi, M., Hu, K., Lu, Z., Streets, D.G., Du, K., Gustafsson, O., 2013a. Source forensics of black carbon aerosols from China. Environ. Sci. Technol. 47, 9102–9108.
Chen, C., Zhu, Z., Liu, D., Wang, Y., Shen, J., 2013b. Pollution characteristics and source apportionment of PM2.5 of ambient air in Zhengzhou. Environ. Monit. China 29,

47–52 (Chinese).
Chen, G., Zhou, X., Wu, J., Tian, Y., Zhou, L., Shi, G., Feng, Y., 2015a. Source apportionment and toxicity quantitation of PM2.5-associated polycyclic aromatic hydrocarbons obtained from Chengdu, China. China Environ. Sci. 35, 3150–3156 (Chinese).
Chen, P., Wang, T., Hu, X., Xie, M., Zhuang, B., Li, S., 2015b. A study of Chemical Mass Balance source apportionment of fine particulate matter in Nanjing. J. Nanjing Univ. (Nat. Sci.) 51, 524–534 (Chinese).
Chen, X., Tang, X., Tian, Y., 2015c. Urban PM2.5 pollution source apportionment and control countermeasures based on PCA-MLR model: an example of Chang-Zhu-Tan city cluster. In: China Soft Science Magazine, pp. 139–149 (Chinese).
Chen, D., Li, M., Huang, B., Jiang, B., Zhang, T., Jiang, M., Xie, M., Zhong, L., Bi, X., Lv, X., Zhang, G., Zhou, Z., 2016a. The pollution characteristics and source apportionment of regional atmospheric fine particles. China Environ. Sci. 36, 651–659 (Chinese).
Chen, G., Liu, J., Huang-Fu, Y., Wang, H., Shi, G., Tian, Y., Zhu, Y., Li, Q., Feng, Y., 2016b. Seasonal variations and source apportionment of ambient PM10 and PM2.5 at urban area of Hefei, China. China Environ. Sci. 36, 1938–1946 (Chinese).
Chen, J., Tang, K., Zhu, Y., Liu, B., 2016c. Pollution characteristics of water-soluble ions in PM2.5 of Hangzhou. J. Zhejiang Univ. Technol. 44, 410–416 (Chinese).
Chen, S., Wang, J., Wang, T., Wang, T., Mai, B., Simonich, S.L., 2016d. Seasonal variations and source apportionment of complex polycyclic aromatic hydrocarbon mixtures in particulate matter in an electronic waste and urban area in South China. Sci. Total Environ. 573, 115–122.
Chen, Y., Chiang, H., Hsu, C.Y., Yang, T., Lin, T., Chen, M., Chen, N., Wu, Y., 2016e. Ambient PM2.5-bound polycyclic aromatic hydrocarbons (PAHs) in Changhua County, central Taiwan: seasonal variation, source apportionment and cancer risk assessment. Environ. Pollut. 218, 372–382.
Chen, P., Wang, T., Lu, X., Yu, Y., Kasoar, M., Xie, M., Zhuang, B., 2017. Source apportionment of size-fractionated particles during the 2013 Asian Youth Games and the 2014 Youth Olympic Games in Nanjing, China. Sci. Total Environ. 579, 860–870.
Cheng, S., Chen, D., Li, J., Wang, H., Guo, X., 2007. The assessment of emission-source contributions to air quality by using a coupled MM5-ARPS-CMAQ modeling system: a case study in the Beijing metropolitan region, China. Environ. Model. Softw. 22, 1601–1616.
Cheng, Y., Li, T., Bai, Y., Li, J., Liu, Z., Wang, X., 2009. Numerical simulation study of SOA in Pearl River Delta region. Environ. Sci. 30, 3441–3447 (Chinese).
Cheng, S., Liu, C., Han, L., Li, Y., Wang, Z., Tian, C., 2014. Characteristics and source apportionment of organic carbon and elemental carbon in PM2.5 during the heating season in Beijing. Journal of Beijing University of Technology 40, 586–591 (Chinese).
Chuang, M., Chen, Y., Lee, C.T., Cheng, C., Tsai, Y.J., Chang, S., Su, Z., 2016. Apportionment of the sources of high fine particulate matter concentration events in a developing aerotropolis in Taoyuan, Taiwan. Environ. Pollut. 214, 273–281.
Cui, L., 2005. Study on the Methods of Analysis and Source Apportionment of Organic Pollutants in Ambient Air. Shandong University, Jinan.
Dai, L., Xue, Y., Feng, Y., Wu, J., 2009. Study on soure apportionment of ambient particulate matter in Chengdu. In: The Academic Annual Meeting of Chinese Society for Environmental Sciences, Wuhan, pp. 805–811.
Ding, S., 2004. Study on the Monitoring of Typical SVOCs in the Ambient Air of Nanjing City. Nanjing University of Science and Technology, Nanjing.
Ding, X., 2012. Study on Distribution Characteristics of Ambient Particulate Matter PM10/PM2.5 Associated PAHs and Source Apportionment in Tianjin. Nankai University, Tianjin.
Ding, W., Wang, Y., Li, L., Feng, Z., 2010. The analysis of Beijing atmospheric pollution characteristics by Positive Matrix Factorization. J. MUC (Nat. Sci. Ed.) 19, 5–12 (Chinese).
Ding, M., Yu, J., Cheng, Z., Chen, Y., 2014. Analysis of PM2.5 ambient particulars emission source of Nanjing. Environ. Sci. Technol. 27, 23–26 (Chinese).
Dong, H., Gu, J., Jiang, W., Bai, Z., 2012. Character and source analysis of chemical element in particulate matters in Tianjin. Admin. Tech. Environ. Monit. 24, 25–28 (Chinese).
Dong, H., Gu, J., Chen, K., Jiang, W., Bai, Z., 2013. Character and source analysis of carbonaceous aerosol in PM2.5 in the center of Tianjin City. Environ. Monit. China 29, 34–38 (Chinese).
Dou, X., Zhao, X., Xu, X., Gao, H., Li, T., Ding, M., Liu, Y., Han, B., Bai, Z., 2016. Source apportionment of PM2.5 in Xining by the chemical mass balance. Environ. Monit. China 32, 7–14 (Chinese).
Duan, J., Li, X., Tan, J., Chai, F., 2009. Size distribution and source apportionment of atmospheric particle number concentration in winter in Beijing. Res. Environ. Sci. 22, 1134–1140 (Chinese).
Fan, S., Xu, J., Zheng, Y., Xie, X., 2005. A sources apportionment of aerosols PM2.5 over the urban and suburb areas of Nanjing. Sci. Meteorol. Sin. 25, 587–593 (Chinese).
Fan, Z., Li, Y., Zhou, H., Liu, H., Yang, Z., 2015. Pollution characteristics and source of water-soluble inorganic ions in PM2.5 in Chengdu. J. China West Normal Univ. (Nat. Sci.) 36, 387–393 (Chinese).
Fan, S., He, J., Meng, Q., Sun, Y., Zhang, J., Zhang, Y., 2016. Analysis of the characteristics and sources of PAHs in fine and coarse particulate matter in four seasons in Nanjing. Trans. Atmos. Sci. 39, 381–390 (Chinese).
Fang, C., Wang, S., Yang, S., Wen, Z., Wang, J., 2015. Source apportionment for atmospheric PM10 in Changchun with PMF and PCA model. Environ. Sci. Technol. 38, 17–21 (Chinese).
Fang, D., Wei, Y., Huang, W., Cai, T., Zhang, Y., Liu, Q., Zhang, Y., 2016. Characterization and source apportionment of organic carbon during a heavy haze episode in Beijing in October 2014. Res. Environ. Sci. 29, 12–19 (Chinese).
Feng, Y., Wu, J., Zhu, T., Bai, Z., Yan, H., Tan, X., 2004. Study on source appointment of TSP and PM10 in air environment in Jinan. Res. Environ. Sci. 17, 1–5 (Chinese).
Feng, Y., Peng, L., Wu, J., Zhu, T., Lu, A., Zhang, K., 2005. Analytic studies on source of TSP and PM10 in environmental air of Urumchi city. China Environ. Sci. 25, 30–33 (Chinese).
Franchini, M., Mannucci, P.M., 2009. Particulate air pollution and cardiovascular risk: short-term and long-term effects. Semin. Thromb. Hemost. 35, 665–670.
Fu, H.B., Chen, J.M., 2017. Formation, features and controlling strategies of severe haze-fog pollutions in China. Sci. Total Environ. 578, 121–138.
Fu, X., Xu, L., Miao, Y., Dong, Y., Jin, T., 2016. On the pollution source apportionment and the characterization of carbon fractions in PM10 at the bus stops in Tianjin. J. Saf. Environ. 16, 309–313 (Chinese).
Gao, S., 2012a. Sources Apportionment of PM10 and PM2.5 in Five Cities in China. Tianjin Medical University, Tianjin.
Gao, X., 2012b. Physical and Chemistry Characteristics of Water-soluble Ions in PM2.5 and Source Apportionment of PM2.5 in Typical Regions of China. Shandong University, Jinan.
Gao, J., Peng, X., Chen, G., Xu, J., Shi, G., Zhang, Y., Feng, Y., 2016. Insights into the chemical characterization and sources of PM2.5 in Beijing at a 1-h time resolution. Sci. Total Environ. 542, 162–171.
Geng, N., 2012. The Analysis and Source Apportionment of Trace Elements in PM2.5 at Zhengzhou High-Tech Zone. Zhengzhou University, Zhengzhou.
Gong, S., 2013. The Distribution and Sources of Organic Nitrogen in PM2.5 in Shanghai, China. Shanghai University, Shanghai.
Gu, Z., 2009. Compositional Variations of Solvent-extractable Organic Compounds in PM2.5 and Their Applications in Source Apportionment. Shanghai University, Shanghai.
Gu, J., Dong, H., Wu, L., Bai, Z., Zhao, J., 2010. Pollution characteristic and source analysis of inorganic elements in PM2.5 in Tianjin. J. Guizhou Univ. Fin. Econ. 495–500 (Chinese).
Gu, J., Wu, L., Huo, G., Bai, Z., Du, S., Liu, A., Xie, Y., 2013. Pollution character and source of water-soluble inorganic ions in PM2.5 over Tianjin. Environ. Monit. China 29, 30–34 (Chinese).
Guo, J., 2015. Study of Chemical Composition Features and Sources Apportionment of Atmospheric Particulate Matter During Haze in Shijiazhuang. Beijing University of Chemical Technology, Beijing.
Guo, H., Ding, A., So, K.L., Ayoko, G., Li, Y., Hung, W.T., 2009. Receptor modeling of source apportionment of Hong Kong aerosols and the implication of urban and regional contribution. Atmos. Environ. 43, 1159–1169.
Hacon, S., Ornelas, C., Ignotti, E., Longo, K., 2007. Fine particulate air pollution and hospital admission for respiratory diseases in the Amazon region. Epidemiology 18, S81.
Han, B., Feng, Y., Bi, X., Xue, Y., Wu, J., Zhu, T., Ding, J., Du, Y., 2009. Source apportionment of ambient PM10 in urban area of Wuxi City. Res. Environ. Sci. 22, 35–39 (Chinese).
Han, L., Zhang, P., Zhang, H., Cheng, S., Wang, H., 2016. Pollution and source apportionment of atmospheric fine particles in Beijing. China Environ. Sci. 36, 3203–3210 (Chinese).
He, L., 2006. Study on analysis of particulate source in the air and its control in Nanning. Yunnan Environmental Science 25, 96–98 (Chinese).
He, K., Zhang, Q., Ma, Y., Yang, F., Cadle, S., Chan, T., Mulawa, P., Chan, C.K., Yao, X., 2002. Source apportionment of PM2.5 in Beijing. Fuel Chemistry Division Preprints 47, 677–678.
Ho, K.F., Cao, J., Lee, S.C., Chan, C.K., 2006. Source apportionment of PM2.5 in urban area of Hong Kong. J. Hazard. Mater. 138, 73–85.
Hopke, P.K., 2016. Review of receptor modeling methods for source apportionment. J. Air Waste Manage. Assoc. 66, 237–259.
Hou, J., 2012. Study on Improved Source Apportionment of PM10 in Urban Atmosphere. Jilin University, Changchun.
Hu, Y., 2016. Characteristics and Source Identification of Polycyclic Aromatic Hydrocarbons (PAHs) in Atmospheric Particulate Matters in Mining City. Anhui University, Hefei.
Hu, S., Zhang, Y., Wei, Y., 2009. Cancer risk level and source apportionment of ambient fine particulate matter in Pearl River Delta. China Environ. Sci. 29, 1202–1208 (Chinese).
Hu, X., Ding, Z., Zhang, Y., Sun, Y., Wu, J., Chen, Y., Lian, H., 2013. Size distribution and source apportionment of airborne metallic elements in Nanjing, China. Aerosol Air Qual. Res. 13, 1796–1806.
Hu, J., Wang, Y., Ying, Q., Zhang, H., 2014a. Spatial and temporal variability of PM2.5 and PM10 over the North China Plain and the Yangtze River Delta, China. Atmos. Environ. 95, 598–609.
Hu, Z., Wang, J., Chen, Y., Chen, Z., Xu, S., 2014b. Concentrations and source apportionment of particulate matter in different functional areas of Shanghai, China. Atmos. Pollut. Res. 5, 138–144.
Hu, J., Ying, Q., Wang, Y., Zhang, H., 2015. Characterizing multi-pollutant air pollution in China: comparison of three air quality indices. Environ. Int. 84, 17–25.
Huang, L., Wang, G., 2014. Chemical characteristics and source apportionment of atmospheric particles during heating period in Harbin, China. J. Environ. Sci. 26, 2475–2483.
Huang, H., Liu, H., Jiang, W., Huang, S., Zhang, Y., 2006. Physical and chemical characteristics and source apportionment of PM2.5 in Nanjing. Clim. Environ. Res. 11, 713–722 (Chinese).
Huang, X., Yu, J., Yuan, Z., Lau, A.K.H., Louie, P.K.K., 2009. Source analysis of high particulate matter days in Hong Kong. Atmos. Environ. 43, 1196–1203.
Huang, R., Zhang, Y., Bozzetti, C., Ho, K., Cao, J., Han, Y., Daellenbach, K.R., Slowik, J.G., Platt, S.M., Canonaco, F., Zotter, P., Wolf, R., Pieber, S.M., Bruns, E.A., Crippa, M., Ciarelli, G., Piazzalunga, A., Schwikowski, M., Abbaszade, G., Schnelle-Kreis, J., Zimmermann, R., An, Z., Szidat, S., Baltensperger, U., Haddad, I.E., Prévôt, A.S.H.,

2014a. High secondary aerosol contribution to particulate pollution during haze events in China. Nature 514, 218–222.
Huang, R.J., Zhang, Y.L., Bozzetti, C., Ho, K.F., Cao, J.J., Han, Y.M., Daellenbach, K.R., Slowik, J.G., Platt, S.M., Canonaco, F., Zotter, P., Wolf, R., Pieber, S.M., Bruns, E.A., Crippa, M., Ciarelli, G., Piazzalunga, A., Schwikowski, M., Abbaszade, G., Schnelle-Kreis, J., Zimmermann, R., An, Z.S., Szidat, S., Baltensperger, U., El Haddad, I., Prevot, A.S.H., 2014b. High secondary aerosol contribution to particulate pollution during haze events in China. Nature 514, 218–222.
Huang, X., Yun, H., Gong, Z., Li, X., He, L., Zhang, Y., Hu, M., 2014c. Source apportionment and secondary organic aerosol estimation of PM2.5 in an urban atmosphere in China. Sci. China Earth Sci. 57, 1352–1362.
Huang, Z., Xiu, G., Zhu, M., Tao, J., Yu, J., 2014d. Characteristics and sources of carbonaceous species in PM2.5 in summer and winter in Shanghai. Environ. Sci. Technol. 37, 124–129 (Chinese).
Huang, S., Pan, Y., Liu, G., Li, M., Bi, Y., 2015. Online source apportionment of atmospheric PM2.5 in Maoming City. Environmental Monitoring and Forewarning 7, 37–42 (Chinese).
Huo, J., Li, P., Han, B., Lu, B., Ding, X., Bai, Z., 2011. Character and source analysis of carbonaceous aerosol in PM2.5 during autumn-winter period, Tianjin. China Environ. Sci. 31, 1937–1942 (Chinese).
Hyslop, N.P., 2009. Impaired visibility: the air pollution people see. Atmos. Environ. 43, 182–195.
Ji, Y., Feng, Y., Wu, J., Zhu, T., Bai, Z., 2006. Characteristics analysis of elements contained in TSP and their apportionment in Tianjin. Environ. Monit. China 22, 75–79 (Chinese).
Jia, L., 2014. Study on Pollution Characteristics and Source Apportionment of Atmospheric Particles on the Northern Cold Region. Harbin Institute of Technology, Harbin.
Jiang, S., Xue, Y., Teng, J., Zhang, L., Wang, Y., Dai, X., 2015. Study on the pollution characteristics and source identification of PAHs on ambient PM2. 5 in fall of Changzhou. Environ. Monit. China 31, 40–44 (Chinese).
Jiao, J., Ji, Y., Bai, Z., Ren, L., Zhou, Z., Zhao, X., 2014. Element distribution characteristics and source apportionment of atmospheric particles in Chongqing. Environ. Pollut. Cont. 36, 60–66 (Chinese).
Kang, P., Jiang, N., Wang, J., Gao, Y., Wei, J., Xu, Y., Yan, Q., Zhang, R., 2015. Study on source apportionment of PM2.5 in winter, spring, summer and autumn from 2013 to 2014 in Zhengzhou. In: The Academic Annual Meeting of Chinese Society for Environmental Sciences, Shenzhen, pp. 3568–3575.
Ke, X., 2015. Pollution Characteristics and Source Analysis of Heavy Metals in Atmospheric Deposition in Chang-Zhu-Tan Area. Ocean University of China, Qingdao.
Kong, S., Han, B., Bai, Z., Chen, L., Shi, J., Xu, Z., 2010. Receptor modeling of PM2.5, PM10 and TSP in different seasons and long-range transport analysis at a coastal site of Tianjin, China. Sci. Total Environ. 408, 4681–4694.
Langrish, J.P., Bosson, J., Unosson, J., Muala, A., Newby, D.E., Mills, N.L., Blomberg, A., Sandstrom, T., 2012. Cardiovascular effects of particulate air pollution exposure: time course and underlying mechanisms. J. Intern. Med. 272, 224–239.
Li, S., 2007. Characterizing the PM2.5 Aerosol and Its Source Apportionment in Urban Guangzhou. Sun Yat-Sen University, Guangzhou.
Li, W., 2010. Pollution Characterizations and Source Apportionment of Polycyclic Aromatic Hydrocarbons in Atmosphere of Xi'an City, China. Xi'an University of Architecture and Technology, Xi'an.
Li, M., 2013. Chemical Composition, Seasonal Variation and Sources of Water-soluble Organic Components in PM2.5 in Shanghai. Shanghai University, Shanghai.
Li, Q.Y., Li, Q., 2016. Research on the pollution characteristics and source apportionment of atmospheric particulates in Sanming downtown area. J. Taishan Univ. 38, 91–95 (Chinese).
Li, W., Bai, Z., Shi, J., Liu, A., 2010. Pollution characteristics and sources of fine particulate matter in ambient air in Tianjin City. Res. Environ. Sci. 23, 394–400 (Chinese).
Li, Y., Yu, J., Ho, S.S.H., Yuan, Z., Lau, A.K.H., Huang, X., 2012. Chemical characteristics of PM2.5 and organic aerosol source analysis during cold front episodes in Hong Kong, China. Atmos. Res. 118, 41–51.
Li, Y., Yu, J., Ho, S.S.H., Schauer, J.J., Yuan, Z., Lau, A.K.H., Louie, P.K.K., 2013. Chemical characteristics and source apportionment of fine particulate organic carbon in Hong Kong during high particulate matter episodes in winter 2003. Atmos. Res. 120-121, 88–98.
Li, L., An, J., Zhou, M., Yan, R., Huang, C., Lu, Q., Lin, L., Wang, Y., Tao, S., Qiao, L., Zhu, S., Chen, C., 2015a. Source apportionment of fine particles and its chemical components over the Yangtze River Delta, China during a heavy haze pollution episode. Atmos. Environ. 123, 415–429.
Li, X., Zhang, Q., Zhang, Y., Zheng, B., Wang, K., Chen, Y., Wallington, T.J., Han, W., Shen, W., Zhang, X., He, K., 2015b. Source contributions of urban PM2.5 in the Beijing–Tianjin–Hebei region: changes between 2006 and 2013 and relative impacts of emissions and meteorology. Atmos. Environ. 123, 229–239.
Li, H., Wang, Q., Yang, M., Li, F., Wang, J., Sun, Y., Wang, C., Wu, H., Qian, X., 2016. Chemical characterization and source apportionment of PM2.5 aerosols in a megacity of Southeast China. Atmos. Res. 181, 288–299.
Liang, L., 2015. Characteristics of PM2.5 in Guiyang and Its Source Apportionment. Guizhou Normal University, Guiyang.
Liang, L., Engling, G., Duan, F., Ma, Y., Cheng, Y., Du, Z., He, K., 2015. Composition and source apportionments of saccharides in atmospheric particulate matter in Beijing. Environ. Sci. 36, 3935–3942 (Chinese).
Lin, Y., Ye, Z., Yang, H., Zhang, J., Yin, W., Li, X., 2016. Pollution level and source apportionment of atmospheric particles PM2.5 in southwest suburb of Chengdu in spring. Environ. Sci. 37, 1629–1638 (Chinese).
Liu, H., 2006. Study on Sources Apportionment of Particulate Matter in Luojia Industrial Area of Nanchang City. Nanchang University, Nanchang.
Liu, D., 2014. Study on the Regional Impact of Fine Particulate Matter in Changchun. Jilin University, Changchun.
Liu, Y., 2016a. Pollution Characterizatics and Sources of Polycyclic Aromatic Hydrocarbons in Atmospheric Deposition and PM2.5 of Shanghai. East China Normal University, Shanghai.
Liu, Z., 2016b. Pollution Characteristics and Source Apportionment of PM2.5 in Lanzhou. Lanzhou University, Lanzhou.
Liu, Y., Gan, X., 2014. Study on the sources of PM2.5 in winter in Zhenjiang. Environmental Science Survey 33, 57–61 (Chinese).
Liu, W., Huang, S., Liu, X., Xu, Z., Hang, W., 2001. Source apportionment for total suspended particles and accumulated dust of Nanjing. Scientia Meteorologica Sinica 21, 87–94 (Chinese).
Liu, G., Li, J., Wu, D., Xu, H., 2015a. Chemical composition and source apportionment of the ambient PM2.5 in Hangzhou, China. Particuology 18, 135–143.
Liu, J., Chu, Y., Zhao, X., Yang, W., Xing, Y., Bai, Z., Wang, X., 2015b. Seasonal distribution and source analysis of water-soluble inorganic ions in PM2.5 and PM10 of Xinzhou City. Acta Sci. Nat. Univ. Nankai 48, 103–111 (Chinese).
Liu, J., Jian, L., Wen, S., Qian, S., 2015c. Source apportionment of polycyclic aromatic hydrocarbons in PM2.5 in winter of Haikou. J. Anhui Agric. Sci. 43, 228–230 (Chinese).
Liu, Y., Yu, Q., Pan, Y., Song, X., Zhong, Z., Qiao, Y., Yang, X., 2015d. Pollution source and characteristics of PM2.5 in Harbin suburbs. Environ. Sci. Technol. 38, 70–73 (Chinese).
Liu, B., Song, N., Dai, Q., Mei, R., Sui, B., Bi, X., Feng, Y., 2016a. Chemical composition and source apportionment of ambient PM2.5 during the non-heating period in Taian, China. Atmos. Res. 170, 23–33.
Liu, J., Li, J., Vonwiller, M., Liu, D., Cheng, H., Shen, K., Salazar, G., Agrios, K., Zhang, Y., He, Q., Ding, X., Zhong, G., Wang, X., Szidat, S., Zhang, G., 2016b. The importance of non-fossil sources in carbonaceous aerosols in a megacity of central China during the 2013 winter haze episode: a source apportionment constrained by radiocarbon and organic tracers. Atmos. Environ. 144, 60–68.
Lu, X., Fung, J.C.H., 2016. Source apportionment of sulfate and nitrate over the Pearl River Delta Region in China. Atmosphere 7, 98–110.
Lu, S., Chen, X., Wu, M., Yao, Z., Jiao, Z., Sheng, G., Fu, J., 2008. Chemical elements and their source apportionment of fine particulates (PM2.5) in Shanghai atmosphere. In: International Conference on Bioinformatics & Biomedical Engineering, pp. 3758–3761.
Luan, M., Ji, Y., Wang, W., Zhang, W., Zhao, J., Li, S., Li, J., Fei, S., Zhao, L., 2016. Characteristic and sources of the polluted elements in PM2.5 during autumn of Anshan. Environ. Chem. 35, 2197–2203 (Chinese).
Luo, Y., 2006. Study on Geochemical Characteristics and Sources Apportionment of Particulate Matter in Shaoguan City. Central South University, Changsha.
Luo, D., 2015. Pollution Characteristics and Source Analysis of PM2.5 in Typical Dust Polluted City, Yinchuan. Chinese Research Academy of Environmental Sciences, Beijing.
Ma, F., 2007. Study on a Typical Air Pollution Event Occurring in Beijing and Its Surrounding Regions by Means of Numerical Model. Nanjing University of Information Science & Technology, Nanjing.
Ma, S., Wang, J., Liu, J., Zhao, W., Liu, M., Su, Y., Li, J., 2015. Source identification of organic hydrocarbon in Guangzhou. Environ. Sci. Technol. (Chinese) 38, 178-182.
Ma, S., Wang, L., Wei, Z., Zhang, F., Meng, C., Yang, J., Shi, C., Zhang, H., 2016a. Seasonal variation of PM2.5 and its chemical compositions in Handan, China. Chin. J. Environ. Eng. 10, 3743–3750 (Chinese).
Ma, Y., Cheng, Y., Qiu, X., Lin, Y., Cao, J., Hu, D., 2016b. A quantitative assessment of source contributions to fine particulate matter (PM2.5)-bound polycyclic aromatic hydrocarbons (PAHs) and their nitrated and hydroxylated derivatives in Hong Kong. Environ. Pollut. 219, 742–749.
Meng, C., Wang, L., Su, J., Yang, J., Wei, Z., Zhang, F., Ma, S., 2016. Chemical compositions and source apportionment of PM2.5 in Handan City, Hebei Province. Environ. Sci. Technol. 39, 57–64 (Chinese).
Ostro, B., Hu, J., Goldberg, D., Reynolds, P., Hertz, A., Bernstein, L., Kleeman, M.J., 2015. Associations of mortality with long-term exposures to fine and ultrafine particles, species and sources: results from the California teachers study cohort. Environ. Health Perspect. http://dx.doi.org/10.1289/ehp.1408565.
Peng, X., 2009. Research on Characteristic of Pollution and Sources Apportionment of PM10, PM2.5 in Nanchang City. Nanchang University, Nanchang.
Qi, L., Zhang, Y., Ma, Y., Chen, M., Ge, X., Ma, Y., Zheng, J., Wang, Z., Li, S., 2016. Source identification of trace elements in the atmosphere during the second Asian Youth Games in Nanjing, China: influence of control measures on air quality. Atmospheric Pollution Research 7, 547–556.
Qiao, T., Zhao, M., Xiu, G., Yu, J., 2016. Simultaneous monitoring and compositions analysis of PM1 and PM2.5 in Shanghai: implications for characterization of haze pollution and source apportionment. Sci. Total Environ. 557–558, 386–394.
Qin, X., 2015. Characterization and Sources Analysis of Heavy Metal Aerosols in North Suburb of Nanjing. Nanjing University of Information Science and Technology, Nanjing.
Qiu, L., 2012. Study on the Uncertainty in Source Apportionment of Particulate Matters in Urban Atmosphere. Jilin University, Changchun.
Qiu, X., Duan, L., Gao, J., Wang, S., Chai, F., Hu, J., Zhang, J., Yun, Y., 2016. Chemical composition and source apportionment of PM10 and PM2.5 in different functional areas of Lanzhou, China. J. Environ. Sci. 40, 75-83.
Ren, L., Zhou, Z., Zhao, X., Yang, W., Yin, B., Bai, Z., Ji, Y., 2014. Source apportionment of PM10 and PM2.5 in urban areas of Chongqing. Res. Environ. Sci. 27, 1387–1394 (Chinese).
Sha, W., 2007. The analysis of TSP sources in city with ADMS model. Environmental

Monitoring in China 23, 110–112 (Chinese).
Shao, D., 2004. Study on Source Apportionment of Urban Ambient Characteristic Pollutant TSP in Dalian and Pollution Control System. Dalian University of Technology, Dalian.
Shen, J., Jiao, L., Xu, C., He, X., Ying, F., Hong, S., 2014. Source apportionment of size-resolved ambient fine particulate matter in Hangzhou. Journal of University of Chinese Academy of Sciences 31, 367–373 (Chinese).
Shi, G., 2007. Study on the Combined Application of Factor Analysis and Chemical Mass Balance Model in Source Apportionment of Particulate Matter. Nankai University, Tianjin.
Shi, G., 2010. The Study and Application of the Combined Receptor Models for Ambient Particulate Matter Source Apportionment. Nankai University, Tianjin.
Shi, G., Chen, G., Liu, G., Wang, H., Tian, Y., Feng, Y., 2016a. Source insights into the 11-h daytime and nighttime fine ambient particulate matter in China as well as the synthetic studies using the new Multilinear Engine 2-species ratios (ME2-SR) method. Environ. Manag. 181, 304–311.
Shi, G., Chen, G., Tian, Y., Peng, X., Xu, J., Feng, Y., 2016b. Characteristic and sources of carbon fractions in PM2.5 in Tianjin urban area. Environ. Pollut. Cont. 38, 1–7 (Chinese).
Shi, G., Xu, J., Peng, X., Tian, Y., Wang, W., Han, B., Zhang, Y., Feng, Y., Russell, A.G., 2016c. Using a new WALSPMF model to quantify the source contributions to PM2.5 at a harbour site in China. Atmos. Environ. 126, 66–75.
Shi, Z., Li, J., Huang, L., Wang, P., Wu, L., Ying, Q., Zhang, H., Lu, L., Liu, X., Liao, H., Hu, J., 2017b. Source apportionment of fine particulate matter in China in 2013 using a source-oriented chemical transport model. Sci. Total Environ. 601–602, 1476–1487.
Shi, G., Tian, Y., Ma, T., Song, D., Zhou, L., Han, B., Feng, Y., Russell, A.G., 2017a. Size distribution, directional source contributions and pollution status of PM from Chengdu, China during a long-term sampling campaign. J. Environ. Sci. 56, 1–11.
Solomon, S., Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change. Working Group I, 2007. Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge; New York.
Song, Y., Tang, X., Fang, C., Zhang, Y., Hu, M., Zeng, L., 2002. Source apportionment on fine particles in Beijing. Environ. Sci. 23, 11–16 (Chinese).
Song, Y., Xie, S., Zhang, Y., Zeng, L., Salmond, L.G., Zheng, M., 2006a. Source apportionment of PM2.5 in Beijing using principal component analysis/absolute principal component scores and UNMIX. Sci. Total Environ. 372, 278–286.
Song, Y., Zhang, Y., Xie, S., Zeng, L., Zheng, M., Salmond, L.G., Shao, M., Slanina, S., 2006b. Source apportionment of PM2.5 in Beijing by positive matrix factorization. Atmos. Environ. 40, 1526–1537.
Song, Y., Tang, X., Xie, S., Zhang, Y., Wei, Y., Zhang, M., Zeng, L., Lu, S., 2007. Source apportionment of PM2.5 in Beijing in 2004. J. Hazard. Mater. 146, 124–130.
Song, N., Xu, H., Bi, X., Wu, J., Zhang, Y., Yang, H., Feng, Y., 2015. Source apportionment of PM2.5 and PM10 in Haikou. Res. Environ. Sci. 28, 1501–1509 (Chinese).
Song, X., Yang, S., Shao, L., Fan, J., Liu, Y., 2016. PM10 mass concentration, chemical composition, and sources in the typical coal-dominated industrial city of Pingdingshan, China. Sci. Total Environ. 571, 1155–1163.
State Council of PRC, 2013. Air Pollution Prevention and Control Action Plan. available at. http://www.mep.gov.cn/gkml/hbb/bwj/201309/W020130918412886411956.pdfThe State Council of the People's Republic of China, Beijing.
Sun, J., 2011. Study on Source Profiles and the Application of CMB Model. Lanzhou University, Lanzhou.
Tan, J., Duan, J., Ma, Y., He, K., Cheng, Y., Deng, S., Huang, Y., Si-Tu, S., 2016a. Long-term trends of chemical characteristics and sources of fine particle in Foshan City, Pearl River Delta: 2008–2014. Sci. Total Environ. 565, 519–528.
Tan, J., Duan, J., Zhen, N., He, K., Hao, J., 2016b. Chemical characteristics and source of size-fractionated atmospheric particle in haze episode in Beijing. Atmos. Res. 167, 24–33.
Tang, L., Zhang, Y., Sun, Y., Yu, H., Zhou, H., Wang, Z., Qin, W., Chen, P., Zhang, H., Chen, Y., Jiang, R., 2014. Components and optical properties of submicron aerosol during the lasting haze period in Nanjing. Chin. Sci. Bull. 59, 1955–1966 (Chinese).
Tang, L.L., Tang, L., Hua, Y., Jiang, R., Cui, Y., Cheng, M., Xu, M., 2015. Characteristics and source apportionment of water-soluble ions and elements in PM2.5 in three cities of South Jiangsu in autumn and winter. Trans. Atmos. Sci. 38, 686–693 (Chinese).
Tao, J., 2003. Source Apportionment and Pollution Characteristics of Total Suspend Particulate Aerosols in Chongqing. Chongqing University, Chongqing.
Tao, S., 2016. Pollution characteristics and source apportionment of fine particles in Jiaxing City during the period of the Second World Internet Conference: a case study by single-particle mass spectrometry. Acta Sci. Circumst. 36, 2761–2770 (Chinese).
Tao, J., Chen, G., Zhong, C., 2006. Sources apportionment of TSP in Chongqing. J. Grad. School Chin. Acad. Sci. 23, 489–493 (Chinese).
Tao, J., Chai, F., Zhu, L., Gao, J., Cao, J., Wang, Q., Luo, L., 2011. Characteristics and sources of carbonaceous aerosol in the urban Chengdu during spring of 2009. Acta Sci. Circumst. 31, 2756–2761 (Chinese).
Tao, J., Gao, J., Zhang, L., Zhang, R., Che, H., Zhang, Z., Lin, Z., Jing, J., Cao, J., Hsu, S.C., 2014. PM2.5 pollution in a megacity of southwest China: source apportionment and implication. Atmos. Chem. Phys. 14, 8679–8699.
Tao, J., Zhang, L., Zhang, R., Wu, Y., Zhang, Z., Zhang, X., Tang, Y., Cao, J., Zhang, Y., 2016. Uncertainty assessment of source attribution of PM2.5 and its water-soluble organic carbon content using different biomass burning tracers in positive matrix factorization analysis—a case study in Beijing, China. Sci. Total Environ. 543, 326–335.
Tian, Y., Wu, J., Shi, G., Wu, J., Zhang, Y., Zhou, L., Zhang, P., Feng, Y., 2013. Long-term variation of the levels, compositions and sources of size-resolved particulate matter in a megacity in China. Sci. Total Environ. 463–464, 462–468.
Tian, Y., Shi, G., Han, B., Wu, J., Zhou, X., Zhou, L., Zhang, P., Feng, Y., 2015. Using an improved Source Directional Apportionment method to quantify the PM2.5 source contributions from various directions in a megacity in China. Chemosphere 119, 750–756.
Tian, P., Cao, J., Han, Y., Zhang, N., Zhang, R., Liu, S., 2016a. Pollution characteristics and sources of carbonaceous aerosol in PM2.5 during winter in Guanzhong area. Environ. Sci. 37, 427–433 (Chinese).
Tian, Y., Chen, G., Wang, H., Huang-Fu, Y., Shi, G., Han, B., Feng, Y., 2016b. Source regional contributions to PM2.5 in a megacity in China using an advanced source regional apportionment method. Chemosphere 147, 256–263.
Viana, M., Kuhlbusch, T.A.J., Querol, X., Alastuey, A., Harrison, R.M., Hopke, P.K., Winiwarter, W., Vallius, A., Szidat, S., Prevot, A.S.H., Hueglin, C., Bloemen, H., Wahlin, P., Vecchi, R., Miranda, A.I., Kasper-Giebl, A., Maenhaut, W., Hitzenberger, R., 2008. Source apportionment of particulate matter in Europe: a review of methods and results. J. Aerosol Sci. 39, 827–849.
Wang, G., 2008. Analysis on the contribution of various atmospheric pollutants concentration in Tieling City. Environ. Protect. Sci. 34, 7–9 (Chinese).
Wang, Q., 2015a. Study on Source Apportionment of Ambient PM2.5 in Changzhou. Jiangsu University of Technology, Changzhou.
Wang, Z., 2015b. A Study of the Source Apportionment of PM10, PM2.5 in Guiyang. Guizhou Normal University, Guiyang.
Wang, S., 2016. Source Apportionment of PM2.5 in Atmosphere in Changchun Using PMF and PCA/APCS Methods. Jilin University, Changchun.
Wang, H., Zhuang, Y., Wang, Y., Sun, Y., Yuan, H., Zhuang, G., Hao, Z., 2008. Long-term monitoring and source apportionment of PM2.5/PM10 in Beijing, China. J. Environ. Sci. 20, 1323–1327.
Wang, H., Zhou, Y., Zhuang, Y., Wang, X., Hao, Z., 2009. Characterization of PM2.5/PM2.5–10 and source tracking in the juncture belt between urban and rural areas of Beijing. Chin. Sci. Bull. 54, 2506–2515.
Wang, J., Zhao, X., Ji, Y., Kong, S., Han, B., Bai, Z., Jia, Y., 2012a. Elemental characteristics and source apportionment of PM10 in Fushun. Environ. Monit. China 28, 107–113 (Chinese).
Wang, Z., Han, L., Chen, X., Li, Y., Tian, C., Xie, H., 2012b. Characteristics and sources of PM2.5 in typical atmospheric pollution episodes in Beijing. J. Saf. Environ. 12, 122–126 (Chinese).
Wang, G., Yao, J., Zeng, Y., Huang, Y., Qian, Y., Liu, W., Li, Y., Yuan, N., Liu, S., Shan, J., 2013. Source apportionment of carbonaceous particulate matter in a Shanghai suburb based on carbon isotope composition. Aerosol Sci. Technol. 47, 239–248.
Wang, D., Hu, J., Xu, Y., Lv, D., Xie, X., Kleeman, M., Xing, J., Zhang, H., Ying, Q., 2014a. Source contributions to primary and secondary inorganic particulate matter during a severe wintertime PM2.5 pollution episode in Xi'an, China. Atmos. Environ. 97, 182–194.
Wang, J., Bi, X., Feng, Y., Zhang, Y., Wu, J., Lv, A., 2014b. Pollution characteristics and source apportionment of PM2.5 during heavy pollution process in Urumchi City. Res. Environ. Sci. 27, 113–119 (Chinese).
Wang, L., Wei, Z., Yang, J., Zhang, Y., Zhang, F., Su, J., Meng, C., Zhang, Q., 2014c. The 2013 severe haze over southern Hebei, China: model evaluation, source apportionment, and policy implications. Atmos. Chem. Phys. 14, 3151–3173.
Wang, S.X., Zhao, B., Cai, S.Y., Klimont, Z., Nielsen, C.P., Morikawa, T., Woo, J.H., Kim, Y., Fu, X., Xu, J.Y., Hao, J.M., He, K.B., 2014d. Emission trends and mitigation options for air pollutants in East Asia. Atmos. Chem. Phys. 14, 6571–6603.
Wang, Y., Cao, J., Zhang, N., Xiao, S., Wang, Q., Chen, Y., 2014e. Chemical composition of atmospheric fine particle (PM1) and its effect on visibility in Xi'an. J. Earth Sci. Environ. 36, 94–101 (Chinese).
Wang, Y., Ying, Q., Hu, J., Zhang, H., 2014f. Spatial and temporal variations of six criteria air pollutants in 31 provincial capital cities in China during 2013–2014. Environ. Int. 73, 413–422.
Wang, L., Wei, Z., Wei, W., Fu, J.S., Meng, C., Ma, S., 2015a. Source apportionment of PM2.5 in top polluted cities in Hebei, China using the CMAQ model. Atmos. Environ. 122, 723–736.
Wang, P., Cao, J., Shen, Z., Han, Y., Lee, S., Huang, Y., Zhu, C., Wang, Q., Xu, H., Huang, R., 2015b. Spatial and seasonal variations of PM2.5 mass and species during 2010 in Xi'an, China. Sci. Total Environ. 508, 477–487.
Wang, Q., Zhang, D., Liu, B., Chen, T., Wei, Q., Li, J., Liang, Y., 2015c. Spatial and temporal variations of ambient PM2.5 source contributions using positive matrix factorization. China Environ. Sci. 35, 2917–2924 (Chinese).
Wang, S., Yu, Y., Wang, Q., Lu, Y., Yin, L., Zhang, Y., Lu, X., 2015d. Source apportionment of PM2.5 in Nanjing by PMF. China Environ. Sci. 35, 3535–3542 (Chinese).
Wang, X., Zhao, Q., Cui, H., 2015e. PM2.5 source apportionment at suburb of Shanghai in winter based on real time monitoring. Journal of Nanjing University (Natural Sciences) 51, 517–523 (Chinese).
Wang, Z., Ma, Y., Zheng, J., Li, S., Wang, L., Zhang, Y., 2015f. Source apportionment of aerosols in urban Nanjing based on particle size distribution. Environ. Chem. 34, 1619–1626 (Chinese).
Wang, H., An, J., Cheng, M., Shen, L., Zhu, B., Li, Y., Wang, Y., Duan, Q., Sullivan, A., Xia, L., 2016a. One year online measurements of water-soluble ions at the industrially polluted town of Nanjing, China: sources, seasonal and diurnal variations. Chemosphere 148, 526–536.
Wang, J., Zhang, Y., Feng, Y., Zheng, X., Jiao, L., Hong, S., Shen, J., Zhu, T., Ding, J., Zhang, Q., 2016b. Characterization and source apportionment of aerosol light extinction with a coupled model of CMB-IMPROVE in Hangzhou, Yangtze River Delta of China. Atmos. Res. 178-179, 570–579.
Wang, J., Zhou, M., Liu, B., Wu, J., Peng, X., Zhang, Y., Han, S., Feng, Y., Zhu, T., 2016c. Characterization and source apportionment of size-segregated atmospheric particulate matter collected at ground level and from the urban canopy in Tianjin. Environ. Pollut. 219, 982–992.

Wang, Q., Liu, M., Yu, Y., Li, Y., 2016d. Characterization and source apportionment of PM2.5-bound polycyclic aromatic hydrocarbons from Shanghai city, China. Environ. Pollut. 218, 118–128.

Wang, W., Kong, S., Liu, H., Yan, Q., Yin, Y., Zhang, X., Li, X., 2016e. Sources and risk assessment of heavy metals in PM2.5 around 2014 Spring Festival in Nanjing. China Environ. Sci. 36, 2186–2195 (Chinese).

Wang, X., Nie, Y., Chen, H., Wang, B., Huang, T., Xia, D., 2016f. Pollution characteristics and source apportionment of PM2. 5 in Lanzhou City. Environ. Sci. 37, 1619–1628 (Chinese).

Wang, Y., Jia, C., Tao, J., Zhang, L., Liang, X., Ma, J., Gao, H., Huang, T., Zhang, K., 2016g. Chemical characterization and source apportionment of PM2.5 in a semi-arid and petrochemical-industrialized city, Northwest China. Sci. Total Environ. 573, 1031–1040.

Wang, Y., Li, J., Li, A., Xie, P., Zheng, H., Zhang, Y., Wang, Z., 2016h. Modeling study of surface PM2.5 and its source apportionment over Henan in 2013–2014. Acta Sci. Circumst. 36, 3543–3553 (Chinese).

Wang, P., Ying, Q., Zhang, H., Hu, J., Lin, Y., Mao, H., 2017. Source apportionment of secondary organic aerosol in China using a regional source-oriented chemical transport model and two emission inventories. Environ. Pollut. http://dx.doi.org/10.1016/j.envpol.2017.1010.1122.

Wei, Z., 2014. A Research on Characteristics of PM Pollution in Handan and Calculation Method of Source Apportionment of PM2.5. Hebei University of Engineering, Tianjin.

Wei, Z., Wang, L., Ma, S., Zhang, F., Yang, J., 2015. Source contributions of PM2.5 in the severe haze episode in Hebei cities. Sci. World J. 2015, 1–11.

Willers, S.M., Eriksson, C., Gidhagen, L., Nilsson, M.E., Pershagen, G., Bellander, T., 2013. Fine and coarse particulate air pollution in relation to respiratory health in Sweden. Eur. Respir. J. 42, 924–934.

Wu, X., 2014. Study on Model of Air Pollution in Hangzhou Based on Community Multiscale Air Quality Model. Zhejiang University, Hangzhou.

Wu, D., Fung, J.C.H., Yao, T., Lau, A.K.H., 2013a. A study of control policy in the Pearl River Delta region by using the particulate matter source apportionment method. Atmos. Environ. 76, 147–161.

Wu, H., Zhang, C., Wang, J., Xuan, Z., Chu, C., Feng, Y., Xu, H., 2013b. Comparative study on pollution characteristics and source apportionment of PM10 and PM2.5 in Qingdao. Res. Environ. Sci. 26, 583–589 (Chinese).

Wu, L., Shen, J., Feng, Y., Bi, X., Jiao, L., Liu, S., 2014a. Source apportionment of particulate matters in different size bins during haze and non-haze episodes in Hangzhou City. Res. Environ. Sci. 27, 373–381 (Chinese).

Wu, S., Deng, F., Wei, H., Huang, J., Wang, X., Hao, Y., Zheng, C., Qin, Y., Lv, H., Shima, M., Guo, X., 2014b. Association of cardiopulmonary health effects with source appointed ambient fine particulate in Beijing, China: a combined analysis from the healthy volunteer natural relocation (HVNR) study. Environ. Sci. Technol. 48, 3438–3448.

Wu, J., Zhang, Y., Wang, J., Huang, Y., Chen, T., Yang, S., Zhan, M., Xie, Y., 2016. Source apportionment of PM2.5 in a process of heavy pollution weather in Jinping district, Shantou. Guangzhou Chem. Ind. 44, 138–141 (Chinese).

Xiang, L., Tian, M., Yang, J., Chen, Y., Yang, F., 2016. Pollution characteristics and source apportionment of n-alkanes in PM2.5 in Wanzhou. Acta Sci. Circumst. 36, 1411–1418 (Chinese).

Xiao, M., 2007. Study on Chemical Composition Features and Sources Apportionment of Particulate Matter in Nanchang City. Nanchang University, Nanchang.

Xiao, Z., Bi, X., Feng, Y., Wang, Y., Zhou, J., Fu, X., Weng, Y., 2012. Source apportionment of ambient PM10 and PM2.5 in urban area of Ningbo City. Res. Environ. Sci. 25, 549–555 (Chinese).

Xu, J., Ding, G., Yan, P., Wang, S., Meng, Z., Zhang, Y., Liu, Y., Zhang, X., Xu, X., 2007. Componential characteristics and sources identification of PM2.5 in Beijing. J. Appl. Meteorol. Sci. 18, 645–654 (Chinese).

Xu, Y., Williams, R.H., Socolow, R.H., 2009. China's rapid deployment of SO_2 scrubbers. Energy Environ. Sci. 2, 459–465.

Xu, H., Cao, J., Chow, J.C., Huang, R., Shen, Z., Chen, L., Ho, K.F., Watson, J.G., 2016a. Inter-annual variability of wintertime PM2.5 chemical composition in Xi'an, China: evidences of changing source emissions. Sci. Total Environ. 545–546, 546–555.

Xu, H., Guo, T., Xie, T., Yu, H., Bai, Z., Wang, C., 2016b. Source apportionment of ambient PM2.5 in urban area of Jinhua City. J. Zhejiang Normal Univ. 39, 227–233 (Chinese).

Yan, X., 2011. The Character and Source Apportionment of fine particles PM2.5 in Baoshan District, Shanghai. East China University of Science and Technology, Shanghai.

Yang, W., 2007. The Application of NAA in Airborne Particulate Matter Pollution in Fangshan District. Chengdu University of Technology, Chengdu.

Yang, L., 2008. Characteristics, Source Apportionment and Influence on Visual Range of PM2.5 in Jinan. Shandong University, Jinan.

Yang, T., 2010. Chemical Compositions and Source Apportionment of PM2.5 in Changsha. Central South University, Changsha.

Yang, S., Chen, S., Yuan, B., 2001. The characteristics of 2.5 μm aerosol measurements in Beijing. J. North. Jiao Tong Univ. 25, 50–53 (Chinese).

Yang, W., Yin, Y., Wei, Y., Chen, K., 2010. Characteristics and sources of metal elements in PM2.5 during hazy days in Nanjing. China Environ. Sci. 30, 12–17 (Chinese).

Yang, L., Cheng, S., Wang, X., Nie, W., Xu, P., Gao, X., Yuan, C., Wang, W., 2013. Source identification and health impact of PM2.5 in a heavily polluted urban atmosphere in China. Atmos. Environ. 75, 265–269.

Yang, H., Chen, J., Wen, J., Tian, H., Liu, X., 2016. Composition and sources of PM2.5 around the heating periods of 2013 and 2014 in Beijing: implications for efficient mitigation measures. Atmos. Environ. 124, 378–386.

Yao, Z., Feng, M., Lu, S., Zhang, J., Wang, Q., Feng, J., Wu, M., Sheng, G., Fu, J., 2010. Physicochemical characterization and source apportionment of PM2.5 collected in Shanghai urban atmosphere and at Lin'an background atmospheric monitoring station. China Environ. Sci. 30, 289–295 (Chinese).

Yao, L., Yang, L., Yuan, Q., Yan, C., Dong, C., Meng, C., Sui, X., Yang, F., Lu, Y., Wang, W., 2016. Sources apportionment of PM2.5 in a background site in the North China Plain. Sci. Total Environ. 541, 590–598.

Ye, W., 2011. Study on source apportionment of PM10 and PM2.5 in ambient air of Ningbo. Environ. Pollut. Cont. 33, 66–69 (Chinese).

Yin, L., 2016. Seasonal and Spatial Variations and Potential Sources of Carbon Fractions in Fine Particle Matters in Nanjing. Nanjing University, Nanjing.

Ying, Q., Wu, L., Zhang, H., 2014. Local and inter-regional contributions to PM2.5 nitrate and sulfate in China. Atmos. Environ. 94, 582–592.

Yu, L., Wang, G., Zhang, R., Zhang, L., Song, Y., Wu, B., Li, X., An, K., Chu, J., 2013. Characterization and source apportionment of PM2.5 in an urban environment in Beijing. Aerosol Air Qual. Res. 13, 574–583.

Yu, J., Wang, W., Zhou, J., Xu, D., Zhao, Q., He, L., 2015. Analysis of pollution characteristics and sources of PM2.5 in winter of Ningbo City. Environ. Sci. Technol. 38, 150–155 (Chinese).

Yu, W., Zhou, J., Guo, H., Xiao, J., Qiu, T., 2016. Composition and source of oxygenated organic compounds in PM2.5 in Wuhan industrial district. Environ. Sci. Technol. 39, 156–161 (Chinese).

Yue, W., Li, X., Liu, J., Li, Y., Yu, X., Deng, B., Wan, T., Zhang, G., Huang, Y., He, W., Hua, W., Shao, L., Li, W., Yang, S., 2006. Characterization of PM2.5 in the ambient air of Shanghai city by analyzing individual particles. Sci. Total Environ. 368, 916–925.

Zeng, F., 2011. Study of Distribution Characteristics of the Particulate Matter in Ambient Air in Optical Valley Local Area. Wuhan Huazhong University of Science & Technology, Wuhan.

Zhang, M., 2014a. Source Apportionment and Distribution of Total Suspended Particles During Autumn in Changchun. Jilin University, Changchun.

Zhang, Z., 2014b. Research on Spatial and Temporal Variation Characteristics, Factors, and Source Apportionment of PM2.5. Zhejiang University, Hangzhou.

Zhang, T., 2016a. Study on Chemical Characteristics and Source of Particulate Matter and Heavy Pollution Analysis in Heating Season, Taiyuan. Taiyuan University of Technology, Taiyuan.

Zhang, Y., 2016b. A Study of the Pollution Characteristics of PGE and Trace Elements of PM10, PM2.5 in Guiyang. Guizhou Normal University, Guiyang.

Zhang, Y.-L., Cao, F., 2015. Fine particulate matter (PM2.5) in China at a city level. Sci. Rep. 5, 14884.

Zhang, F., Chen, Z., 2015. Study on the pollution characteristics and source apportionment of particulate matter based on the elements in Baosteel factory district. In: Baosteel Biennial Academic Conference, Shanghai.

Zhang, X., Zhuang, M., 2007. Study on Source Apportionment of Ambient Fine Particulate Matter PM2.5 in Xiamen. Xiamen Science & Technology, pp. 41–43 (Chinese).

Zhang, Y., Tang, X., Bi, M., Tang, D., Zhao, D., 1987. Identification of pollutant sources of aerosol in Xigu area, Lanzhou. Acta Sci. Circumst. 7, 269–278 (Chinese).

Zhang, W., Guo, J., Sun, Y., Yuan, H., Zhuang, G., Zhuang, Y., Hao, Z., 2007. Source apportionment for urban PM10 and PM2.5 in the Beijing area. Chin. Sci. Bull. 52, 608–615.

Zhang, H., Li, J., Ying, Q., Yu, J., Wu, D., Cheng, Y., He, K., Jiang, J., 2012. Source apportionment of PM2.5 nitrate and sulfate in China using a source-oriented chemical transport model. Atmos. Environ. 62, 228–242.

Zhang, R., Jing, J., Tao, J., Hsu, S.C., Wang, G., Cao, J., Lee, C.S.L., Zhu, L., Chen, Z., Zhao, Y., Shen, Z., 2013a. Chemical characterization and source apportionment of PM2.5 in Beijing: seasonal perspective. Atmos. Chem. Phys. 13, 7053–7074.

Zhang, Z., Tao, J., Xie, S., Zhou, L., Song, D., Zhang, P., Cao, J., Luo, L., 2013b. Seasonal variations and source apportionment of PM2.5 at urban area of Chengdu. Acta Sci. Circumst. 33, 2947–2952 (Chinese).

Zhang, C., Zhou, Z., Zhai, C., Bai, Z., Chen, G., Ji, Y., Ren, L., Fang, W., 2014. Carbon source apportionment of PM2.5 in Chongqing based on local carbon profiles. Environ. Sci. 35, 810–819 (Chinese).

Zhang, F., Wang, L., Su, J., Yang, J., Wei, Z., Meng, C., Zheng, Y., 2015a. Characteristics and source apportionment of carbonaceous species in PM2.5 of Handan City. Environ. Sci. Technol. 38, 94–100 (Chinese).

Zhang, Y., Zheng, M., Cai, J., Yan, C., Hu, Y., Ag, R., Wang, X., Wang, S., Zhang, Y., 2015b. Comparison and overview of PM2.5 source apportionment methods. Chin. Sci. Bull. 60, 109–121 (Chinese).

Zhang, D., Nan, S., Wang, W., Zhao, X., Duo, K., Zhang, J., 2016a. Distribution characteristics and source apportionment of PAHs in atmosphere and particulates in Zhengzhou. Environ. Monit. Forew. 8, 48–52 (Chinese).

Zhang, F., Zheng, L., Wang, X., 2016b. Pollution Characteristics and Source Apportionment of Ambient PM2.5 in Baoshan Iron & Steel Co., Ltd. Baosteel Technology, pp. 60–64 (Chinese).

Zhang, L., Wang, C., Zhu, H., Yu, H., Lv, Y., 2016c. Characterization and source apportionment of PM2.5 in mixed function area during summer and winter, Beijing. China Environ. Sci. 36, 36–41 (Chinese).

Zhang, Y., Ma, Y., Qi, L., Wang, Z., Wang, L., Zhu, L., 2016d. Determination and source apportionment of aromatic acids in PM2.5 from the northern suburb of Nanjing in winter. Environ. Sci. 37, 2436–2442 (Chinese).

Zhang, Z., Hu, G., Yu, R., Liu, X., Hu, Q., Wang, X., 2016e. Characteristics and source apportionment of metals in the dustfall of Quanzhou City. Environ. Sci. 37, 2881–2888 (Chinese).

Zhang, Y., Cai, J., Wang, S., He, K., Zheng, M., 2017. Review of receptor-based source apportionment research of fine particulate matter and its challenges in China. Sci. Total Environ. 586, 917–929.

Zhao, L., 2005. Characteristics of Toxic Air Pollutants and Their Sources in Urban Guangzhou Streets. University of Chinese Academy of Sciences, Beijing.

Zhao, Q., He, K., Ma, Y., Jia, Y., Cheng, Y., Liu, H., Wang, S., 2009. Regional PM pollution in Beijing and surrounding area during summertime. Environ. Sci. 30, 1873–1880

(Chinese).
Zhao, J., Ji, Y., Shan, C., Wang, W., Li, J., Ding, L., Zhang, S., Zhu, Z., 2015. Composition characteristics and source analysis of PAHs in PM2.5 in Anshan City in summer. Environ. Pollut. Cont. 37, 72–75 (Chinese).
Zhao, Y., Lin, X., Hu, G., Yu, R., 2016. Pollution characteristics, risk assessment and source analysis of polycyclic aromatic hydrocarbons in PM2.5 collected in autumn in Nanchang City. Environ. Chem. 35, 500–507 (Chinese).
Zheng, Y., Lv, J., 2015. Pollution characteristics and sources analysis of elements in PM2.5. Sci. Technol. Eng. 15, 58–62 (Chinese).
Zheng, M., Salmon, L.G., Schauer, J.J., Zeng, L., Kiang, C.S., Zhang, Y., Cass, G.R., 2005. Seasonal trends in PM2.5 source contributions in Beijing, China. Atmos. Environ. 39, 3967–3976.
Zheng, M., Zhang, Y., Yan, C., Zhu, X., Schauer, J.J., Zhang, Y., 2014. Review of PM2.5 source apportionment methods in China. Acta Sci. Circumst. 50, 1141–1154 (Chinese).
Zhou, Y., Zhang, H., Wang, Q., Xu, L., Wang, C., 2015. Pollution characteristics and source apportionment of PM2.5 from Qinshan District in Wuhan during the winter. Environ. Sci. Technol. 38, 159–164 (Chinese).
Zhou, H., Du, Y., Dudagula, Liu, T., Wei, X., Yan, L., He, J., 2016a. Characterization and source apportionment of polycyclic aromatic hydrocarbons bound to PM10 during winter in Hohhot. Environ. Chem. 35, 1707–1714 (Chinese).
Zhou, L., Shi, G., Fu, Y., Guan, Y., Chen, L., 2016b. Preliminary study on the microscopic morphology and chemical composition, and its source of PM2.5 in Guangzhou. Rock Miner. Anal. 35, 302–309 (Chinese).
Zhu, T., Bai, Z., Chen, W., 1995. Source analysis of air particulate in Qinhuangdao city. Res. Environ. Sci. 8, 49–55 (Chinese).
Zhu, T., Bai, Z., Chen, W., Xie, X., 1996. Application of receptor model-chemical mass balance—source apportionment for air particulate matters in TEDA. Urban Environ. Urban Ecol. 9, 9–14 (Chinese).
Zhu, X., Zhang, Y., Zeng, L., Wang, W., 2005. Source identification of ambient PM2.5 in Beijing. Res. Environ. Sci. 18, 1–5 (Chinese).
Zhuang, X.L., Wang, Y.S., He, H., Liu, J.G., Wang, X.M., Zhu, T.Y., Ge, M.F., Zhou, J., Tang, G.Q., Ma, J.Z., 2014. Haze insights and mitigation in China: an overview. J. Environ. Sci. 26, 2–12.